



# Inter-Procedural Analysis

CMPUT 497/500  
Foundations of Program Analysis

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# Previously

- Points-to
- Aliases
- Must and May analyses
- Incomplete Programs
- Weak vs Strong Updates
- Access Paths
- Distributivity

# Inter-Procedural Data-Flow Analysis

- Beyond procedure boundaries
- Model the effects of
  - calls in the callers, and
  - calling contexts in the callees

# Inter-Procedural Data-Flow Analysis

- Approaches
  - Generic: Call-strings approach, functional approach
  - Problem specific: Alias analysis, Points-to analysis, Partial redundancy elimination, Constant propagation

# Inter-Procedural Data-Flow Analysis

fun s()

fun r()

fun t()

# Inter-Procedural Data-Flow Analysis

fun s()  
Ss

fun r()  
Sr

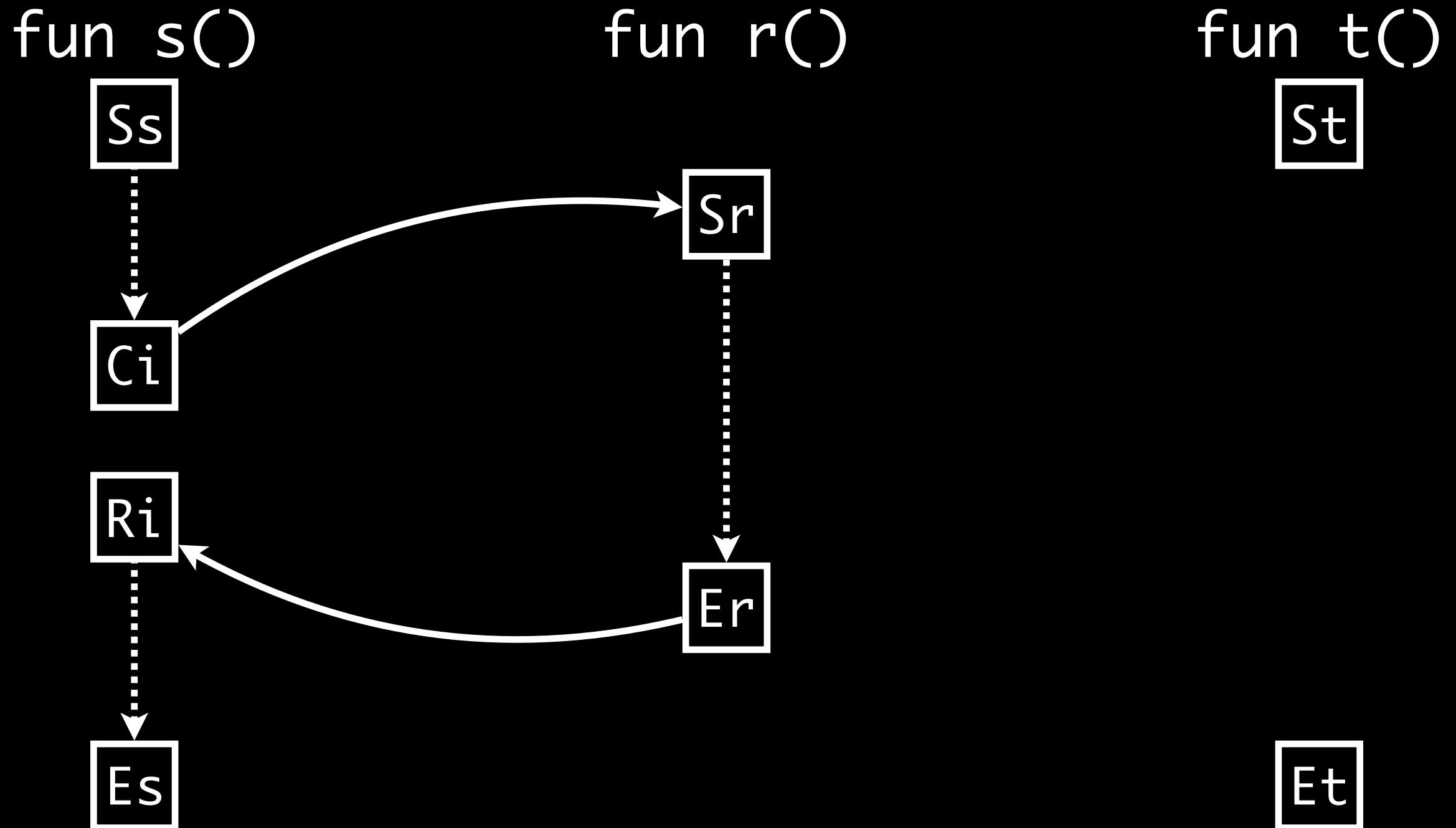
fun t()  
St

Es

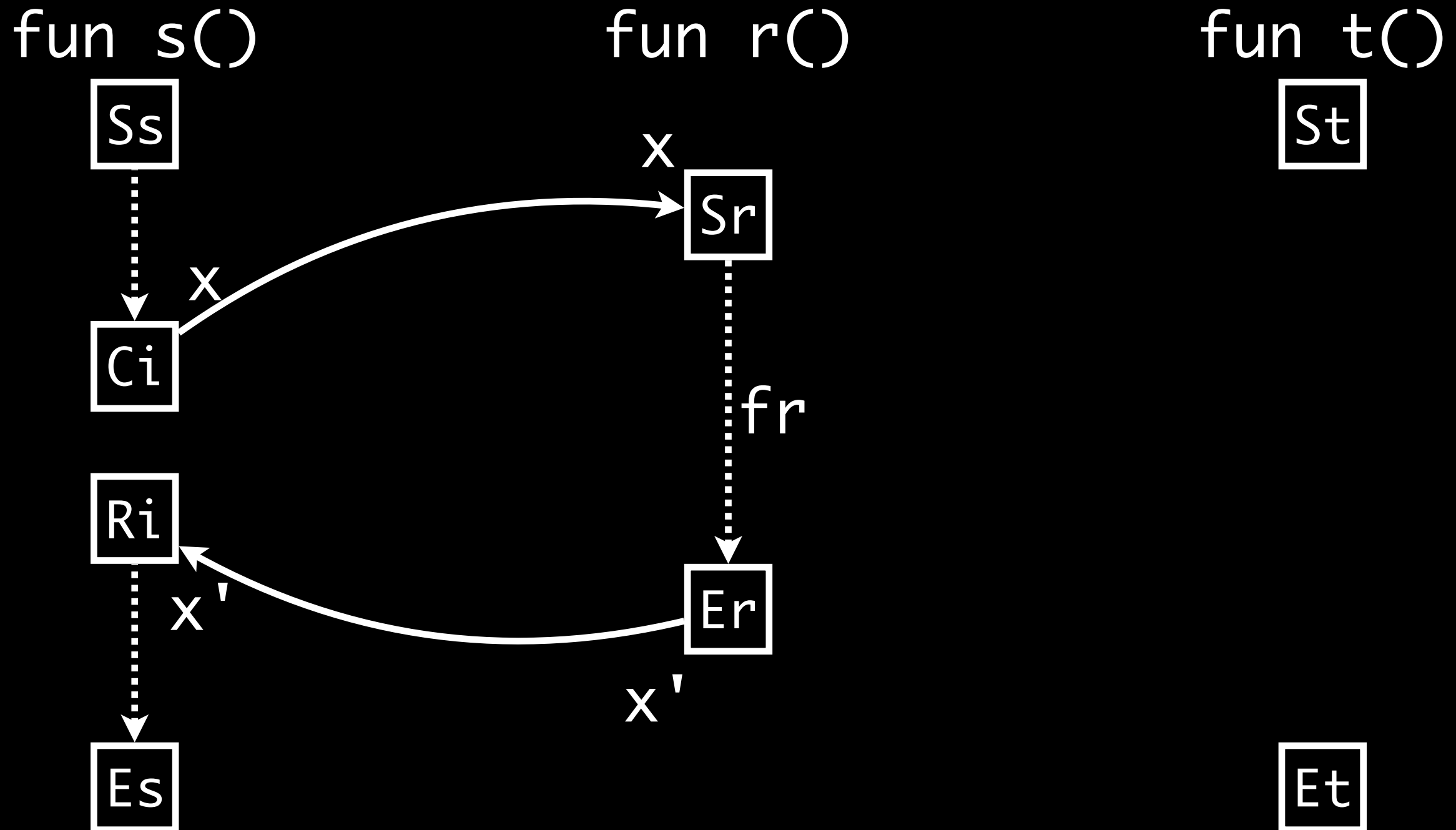
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# Inter-Procedural Data-Flow Analysis

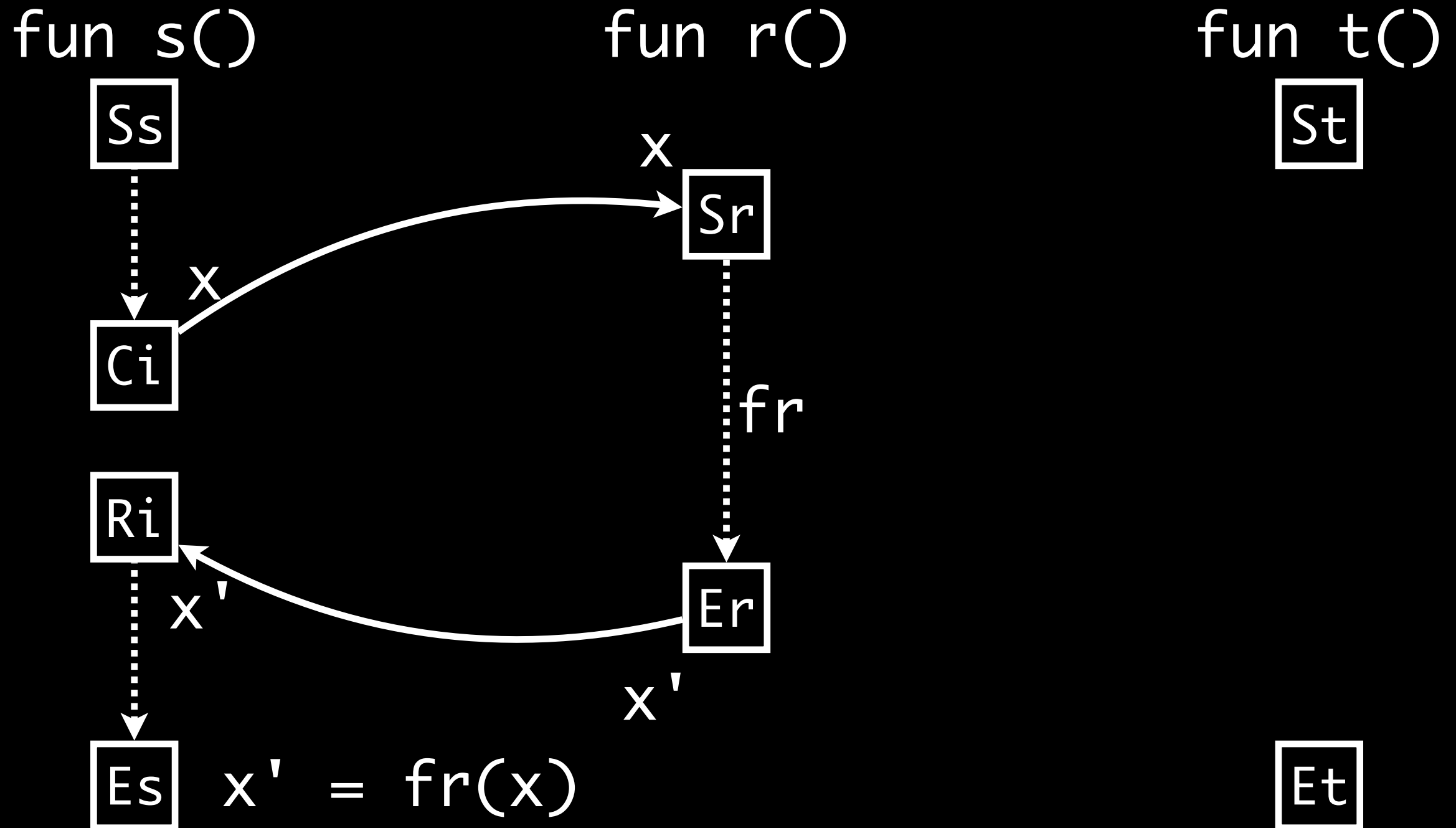


# Inter-Procedural Data-Flow Analysis

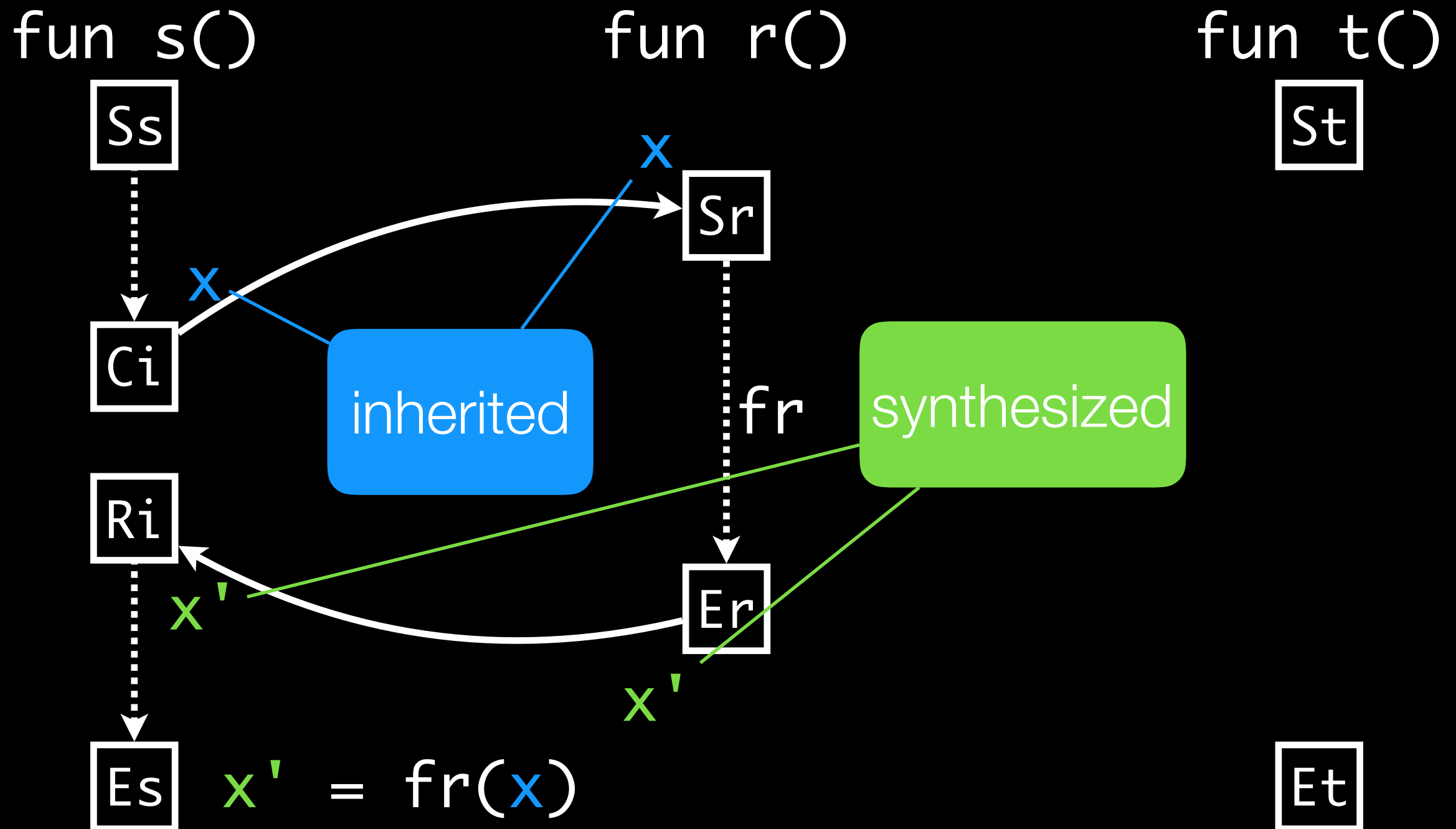




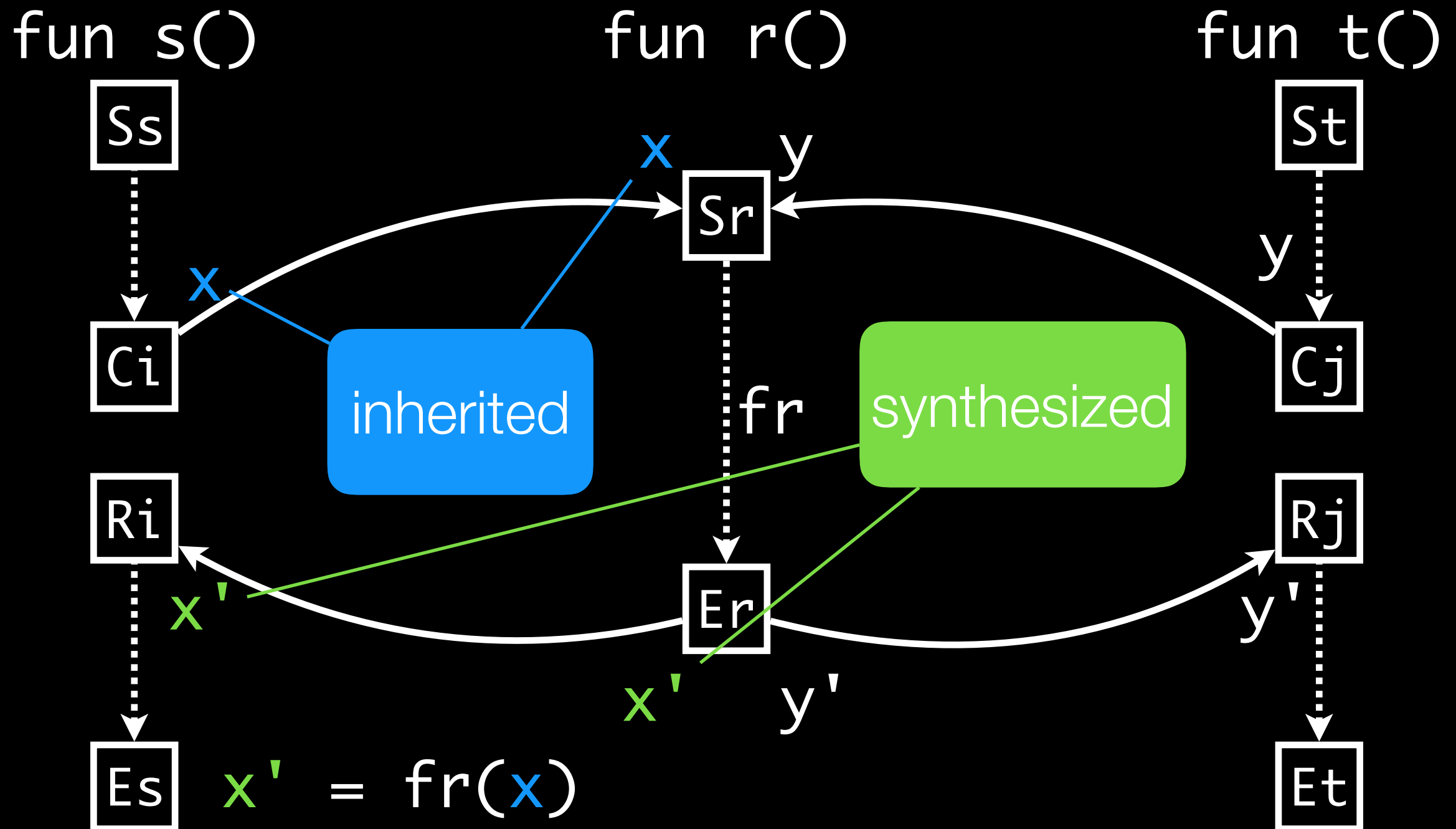
# Inter-Procedural Data-Flow Analysis



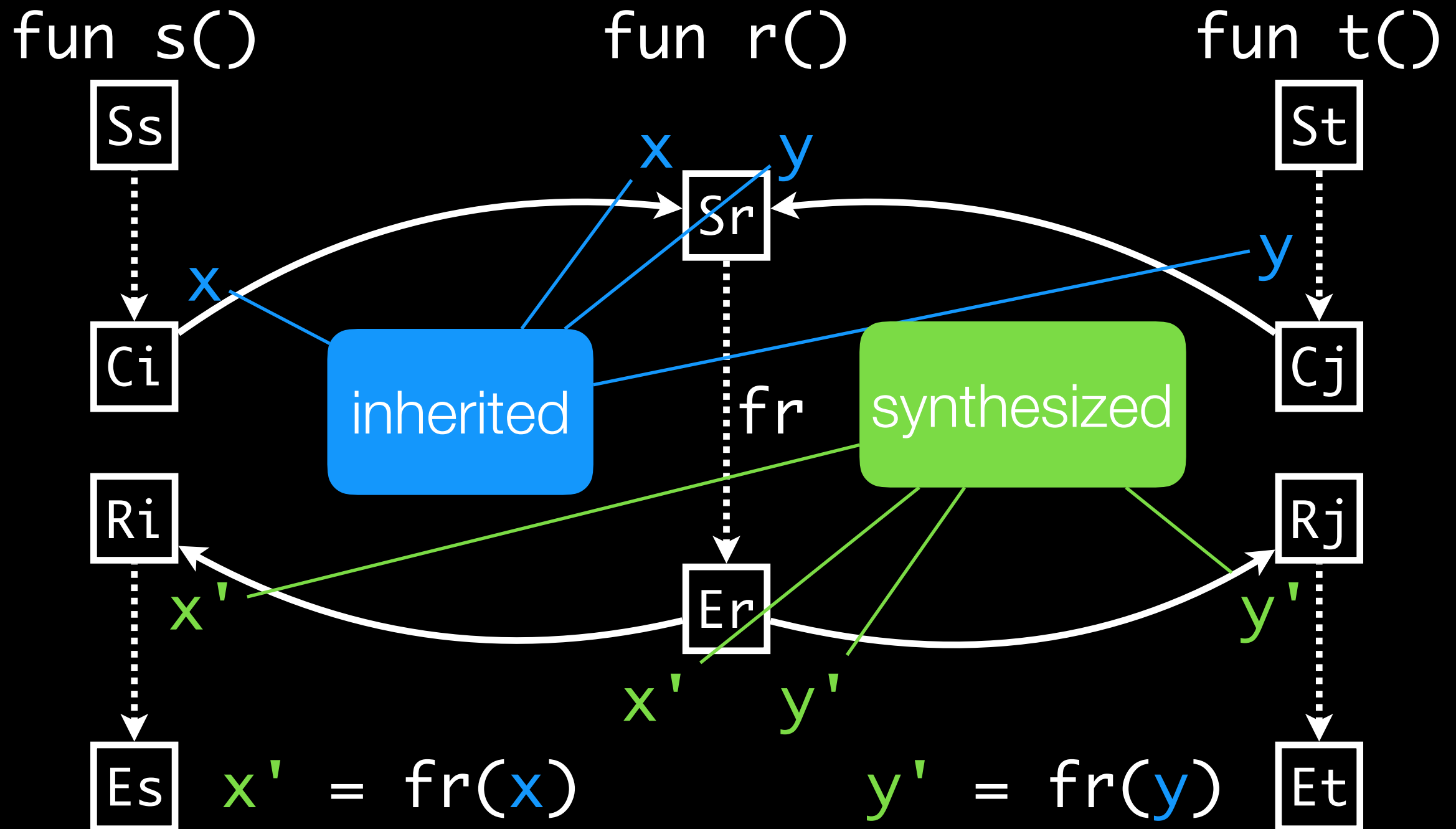
# Inter-Procedural Data-Flow Analysis



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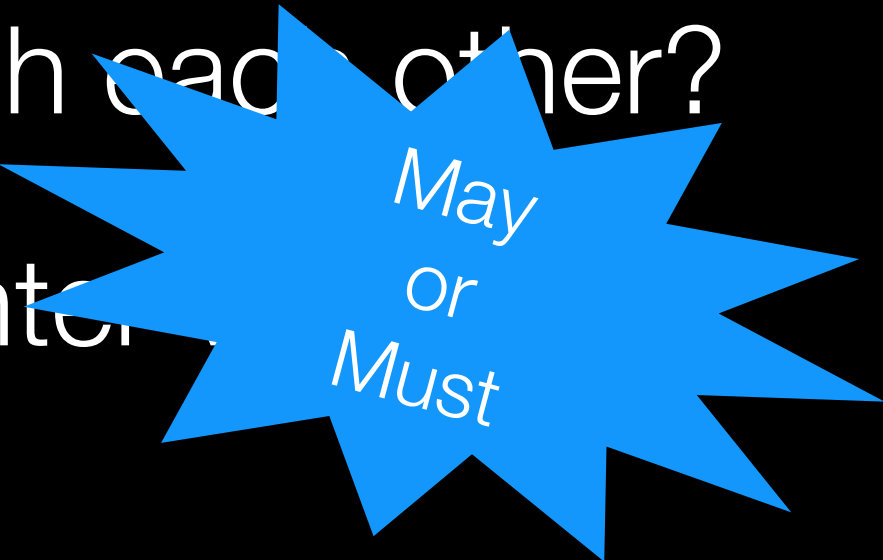
# Inter-Procedural Data-Flow Analysis



# Inherited vs Synthesized Analysis Information

# Inherited Analysis Information

- Answering questions about formal parameters and global variables:
  - Which variables carry constant values?
  - Which variables aliased with each other?
  - Which locations can a pointer point to?



May  
or  
Must

# Synthesized Analysis Information

- Answering questions about side-effects of a procedure call:
  - Which local/global/formal variables are defined in a callee?
  - Which local/global/formal variables are used by a callee?



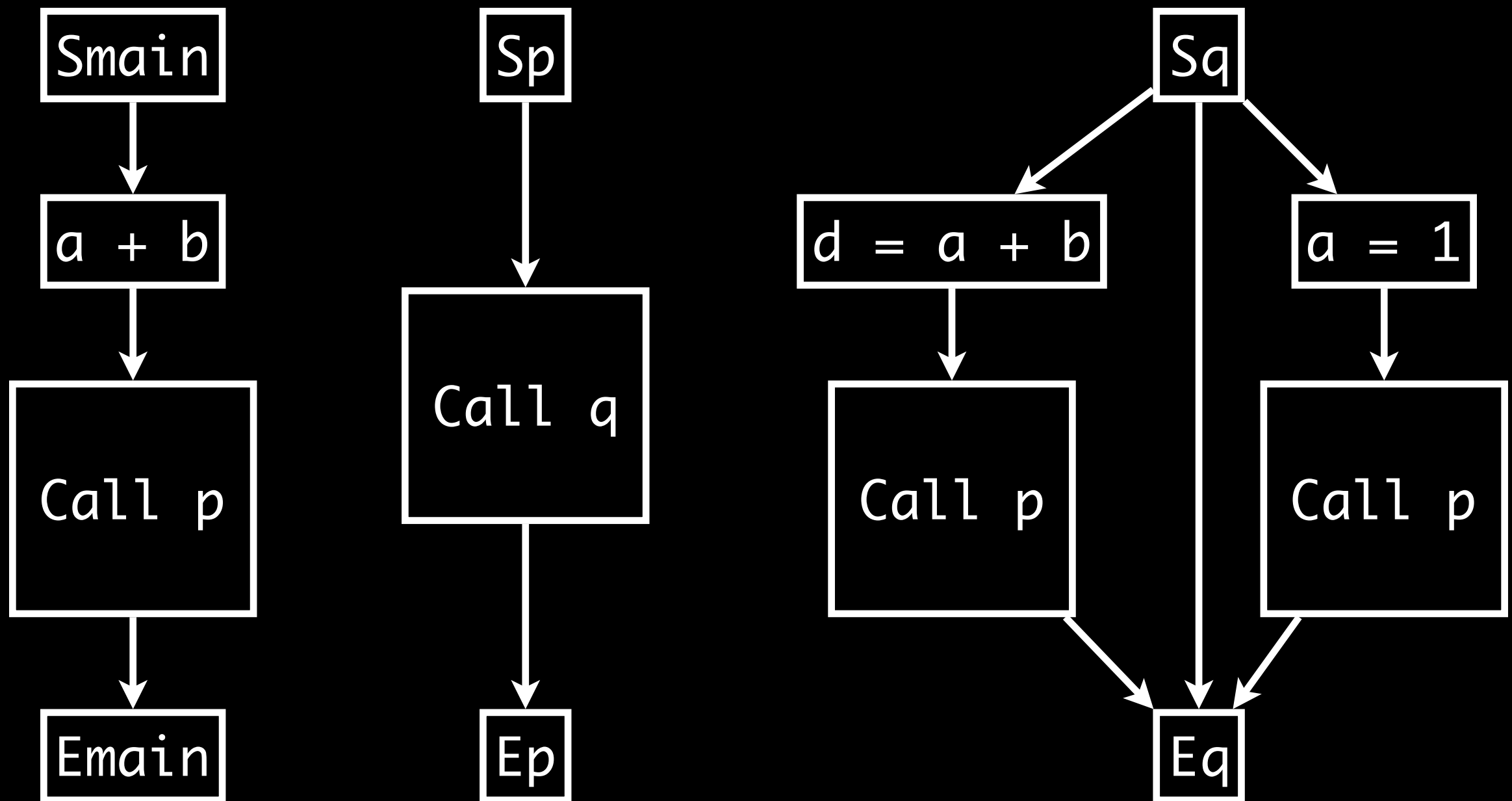
May  
or  
Must

# Inter-Procedural Control-Flow Graph (ICFG)

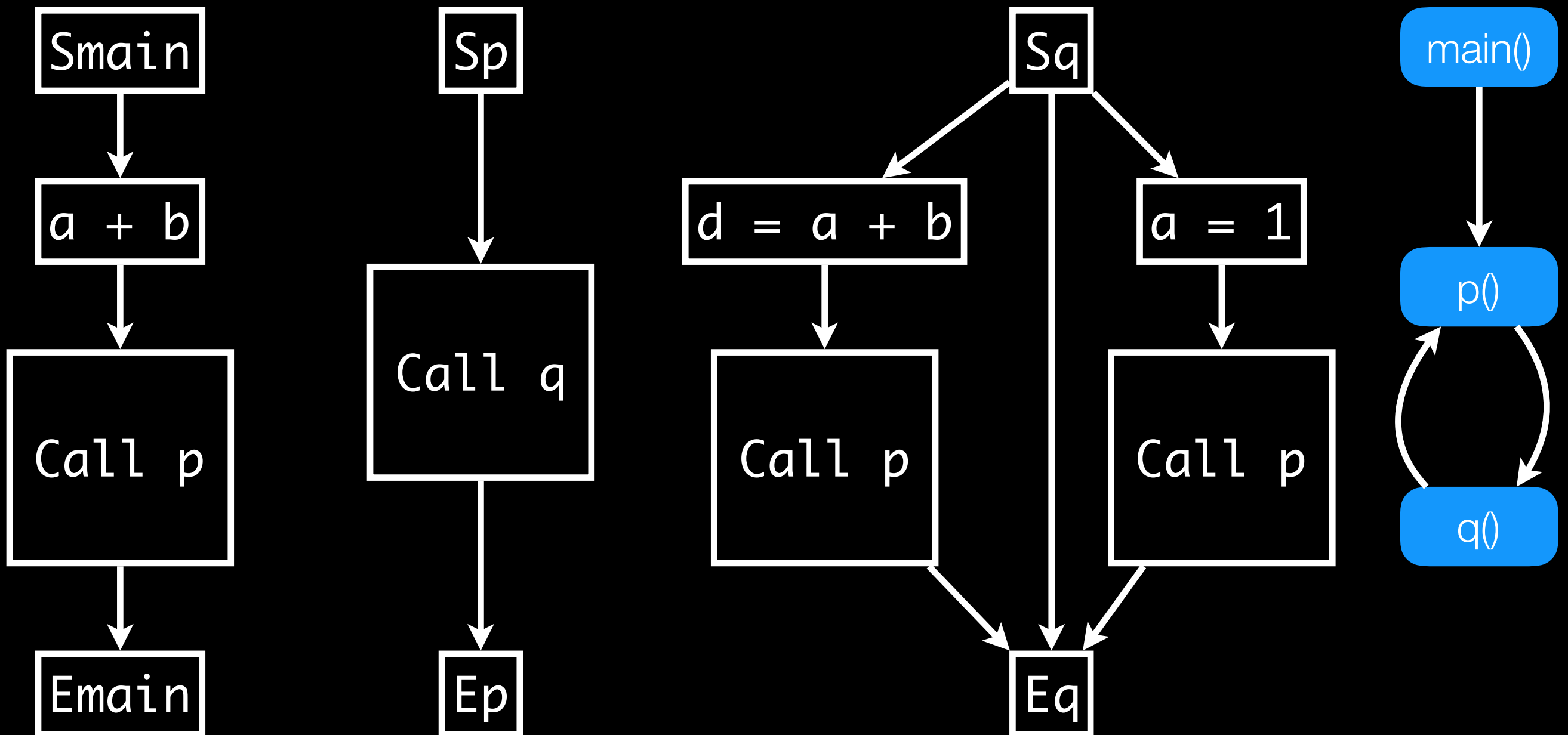
aka “program super-graph”



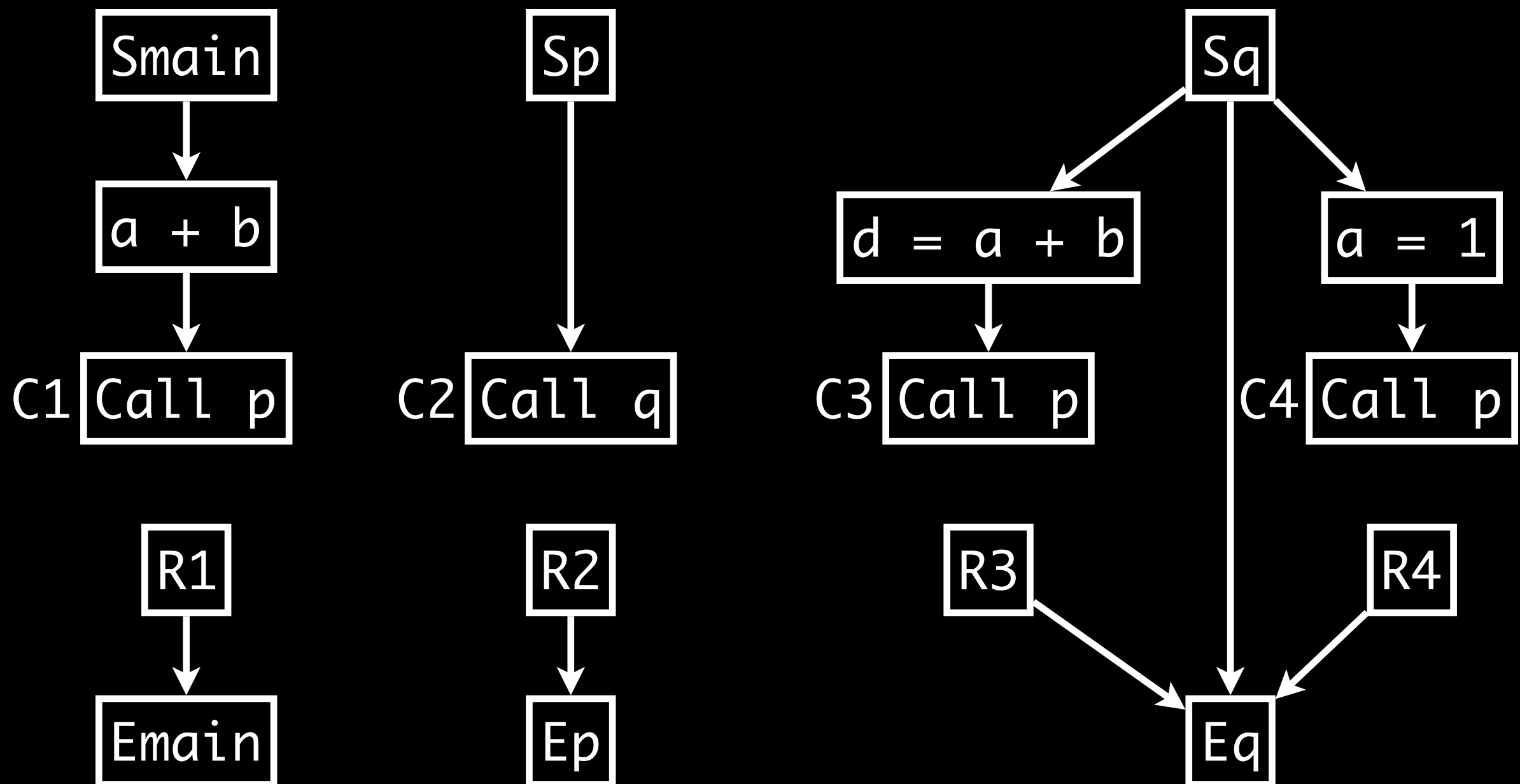
# Procedure Space



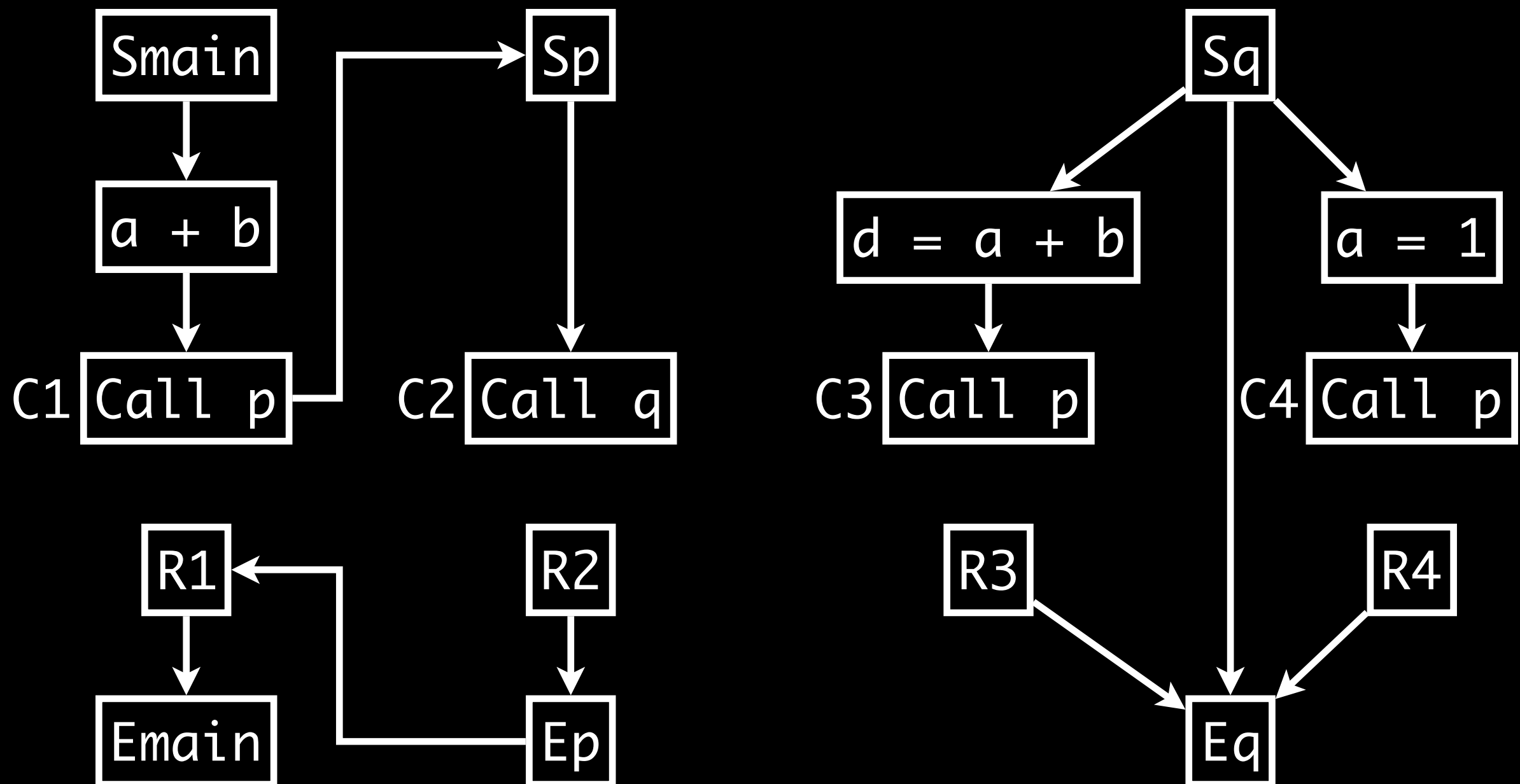
# Call Graph



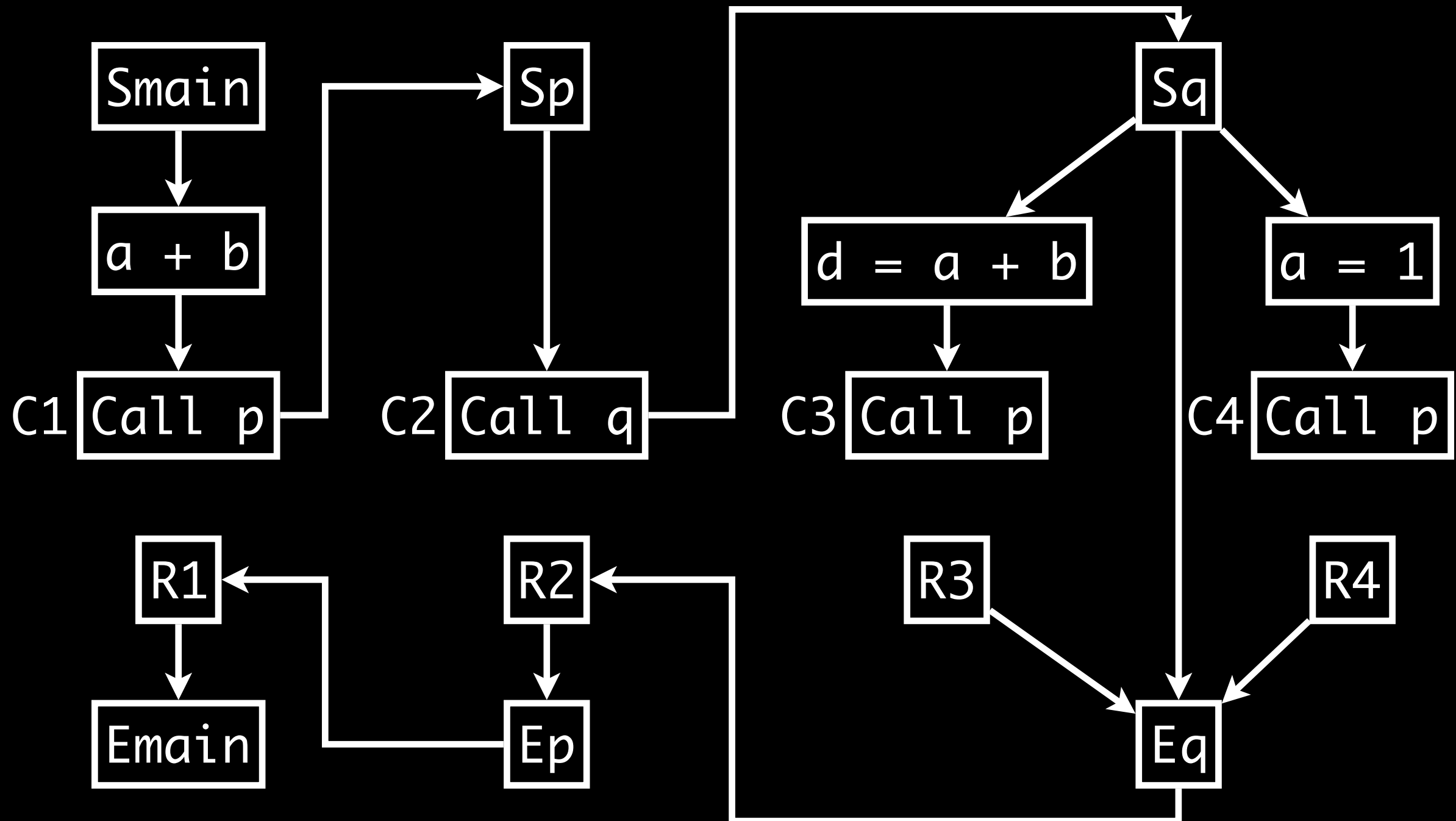
# Introduce Return Sites



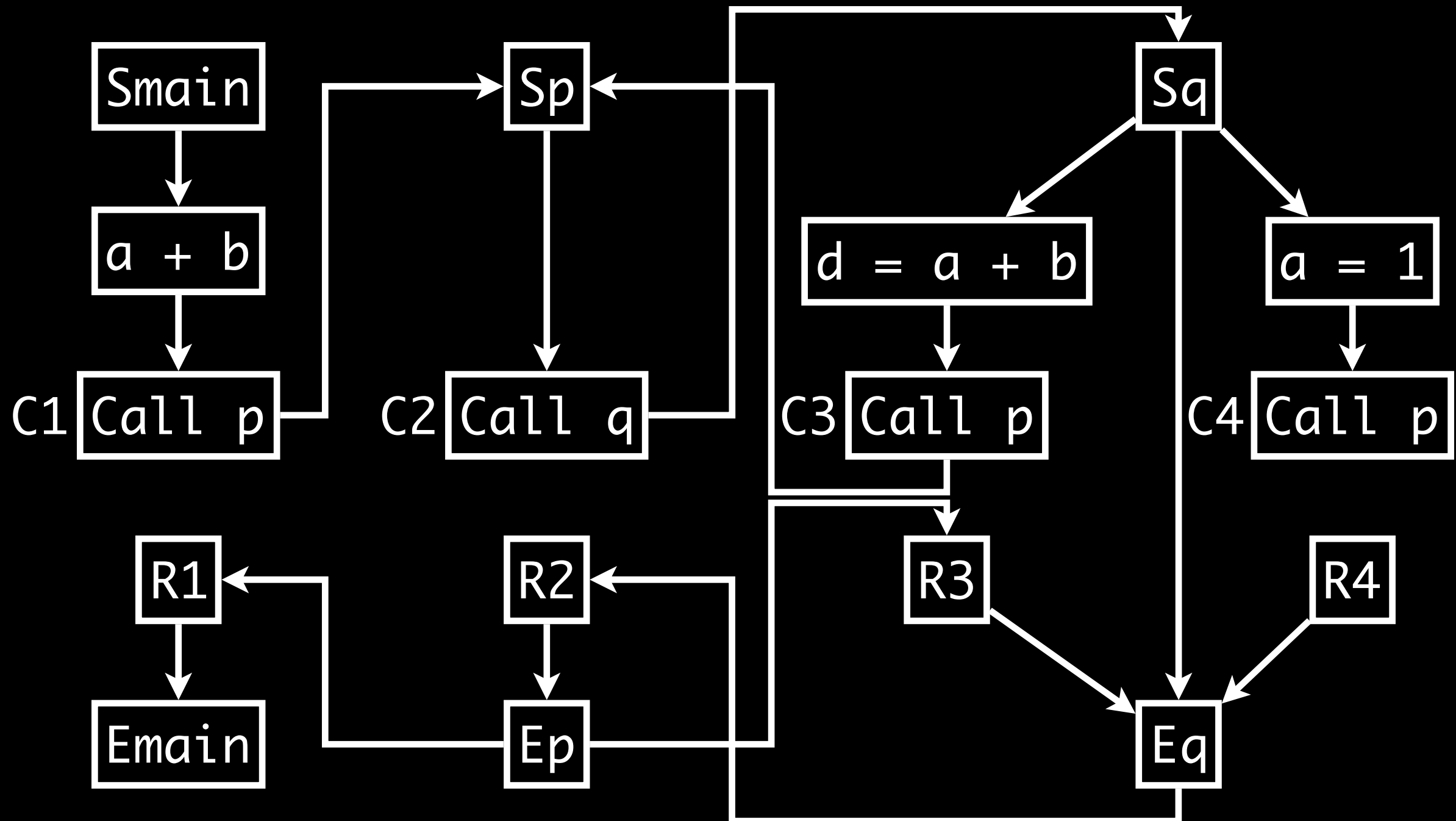
# Caller-Callee Relationships



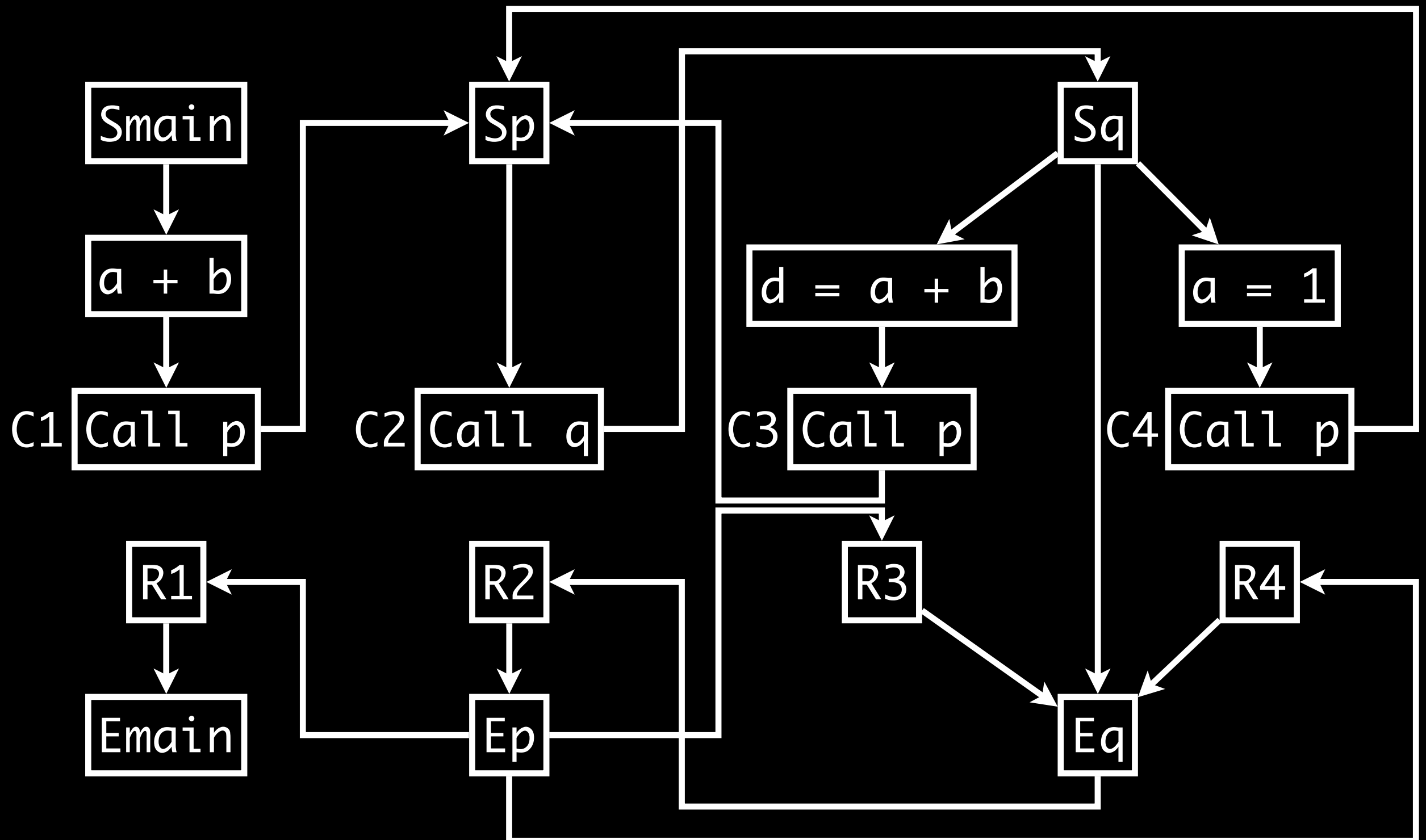
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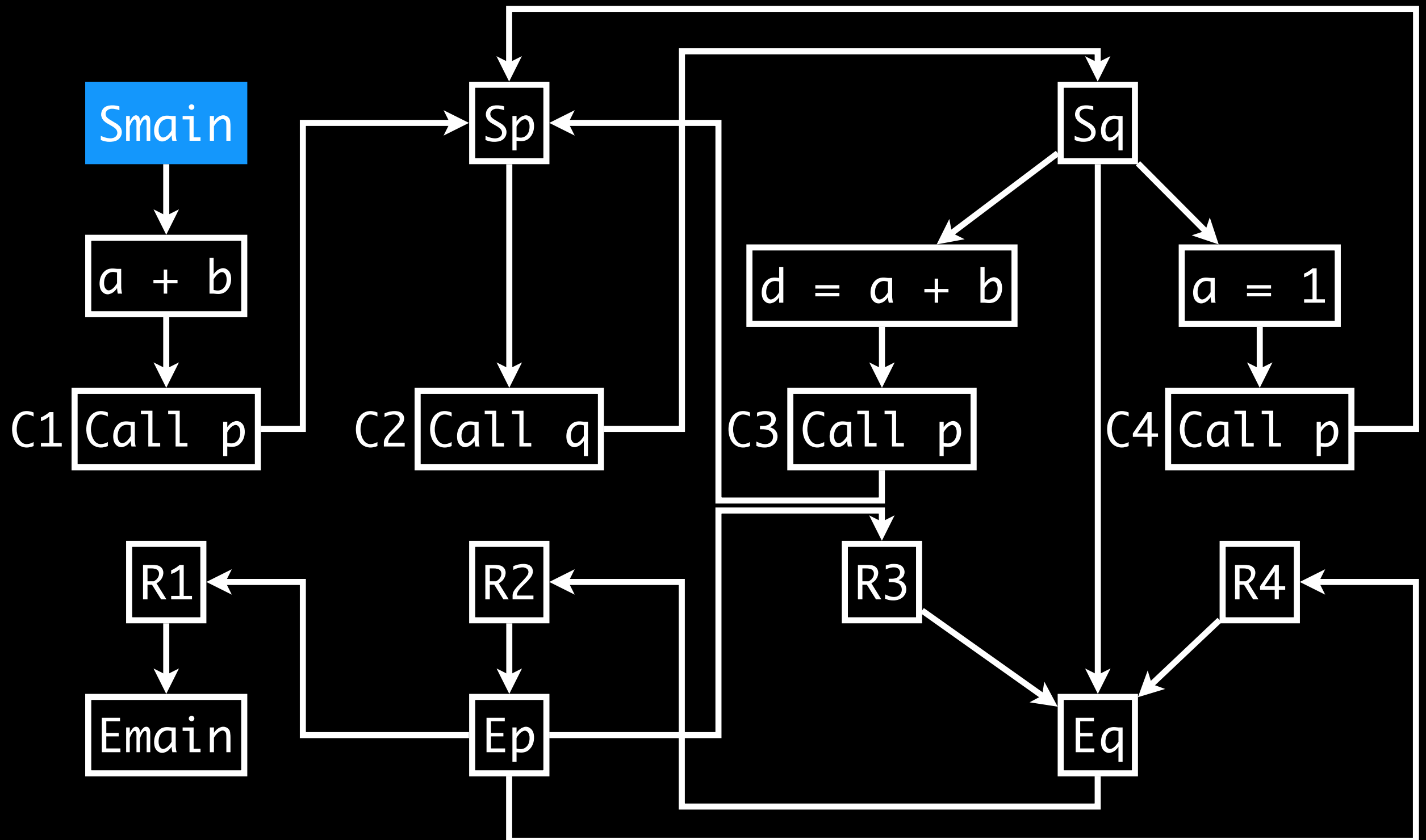
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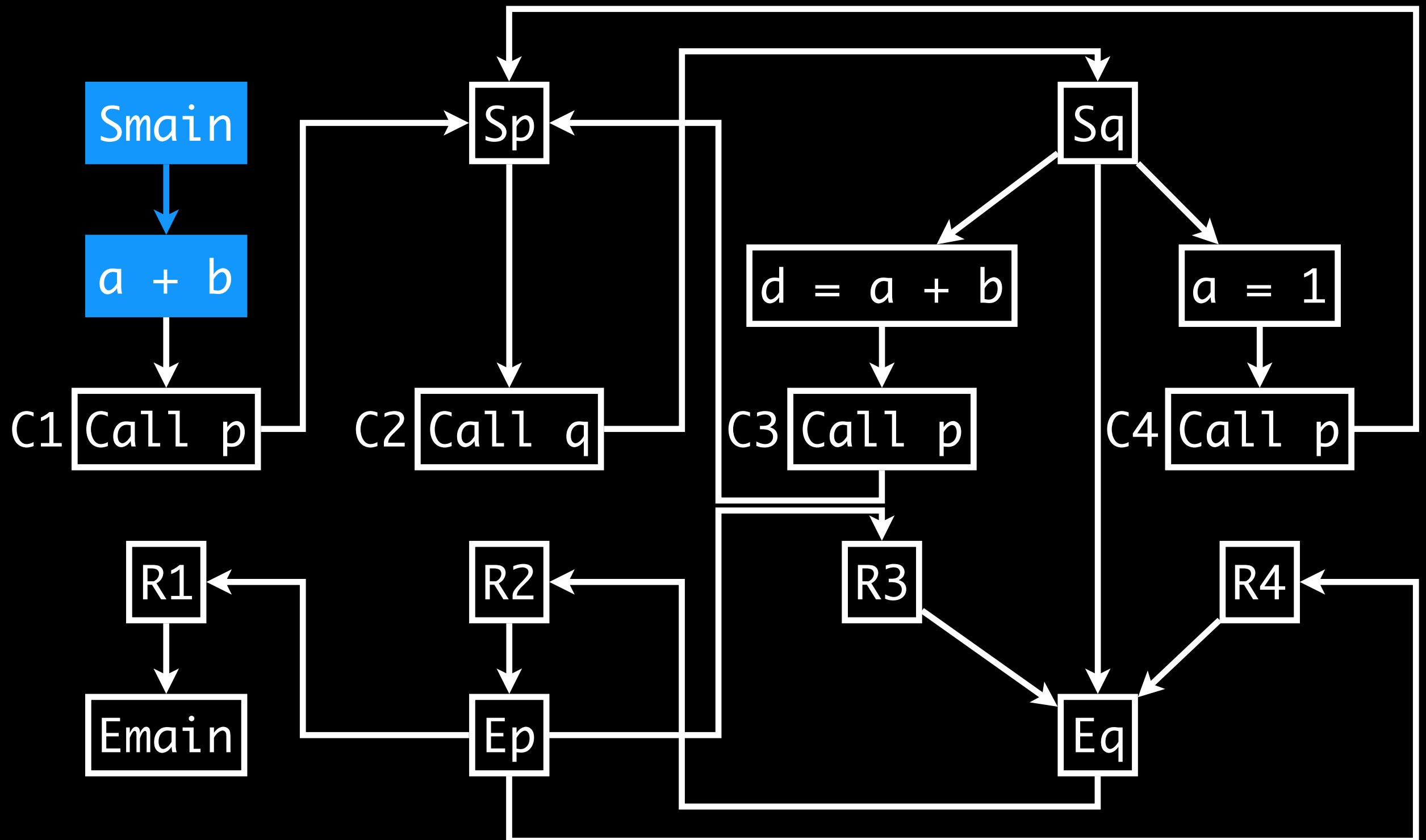


# Valid/Realizable Path

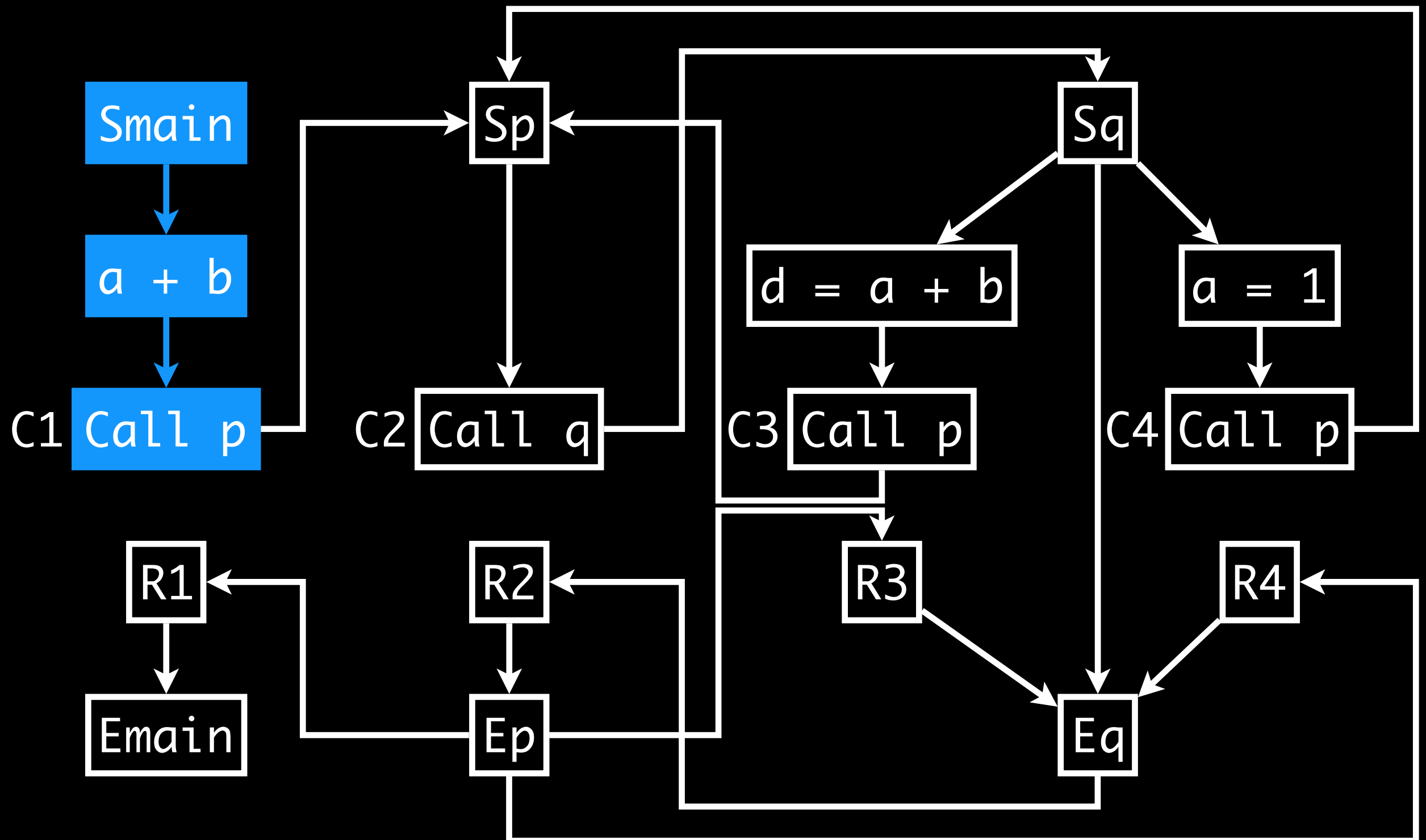




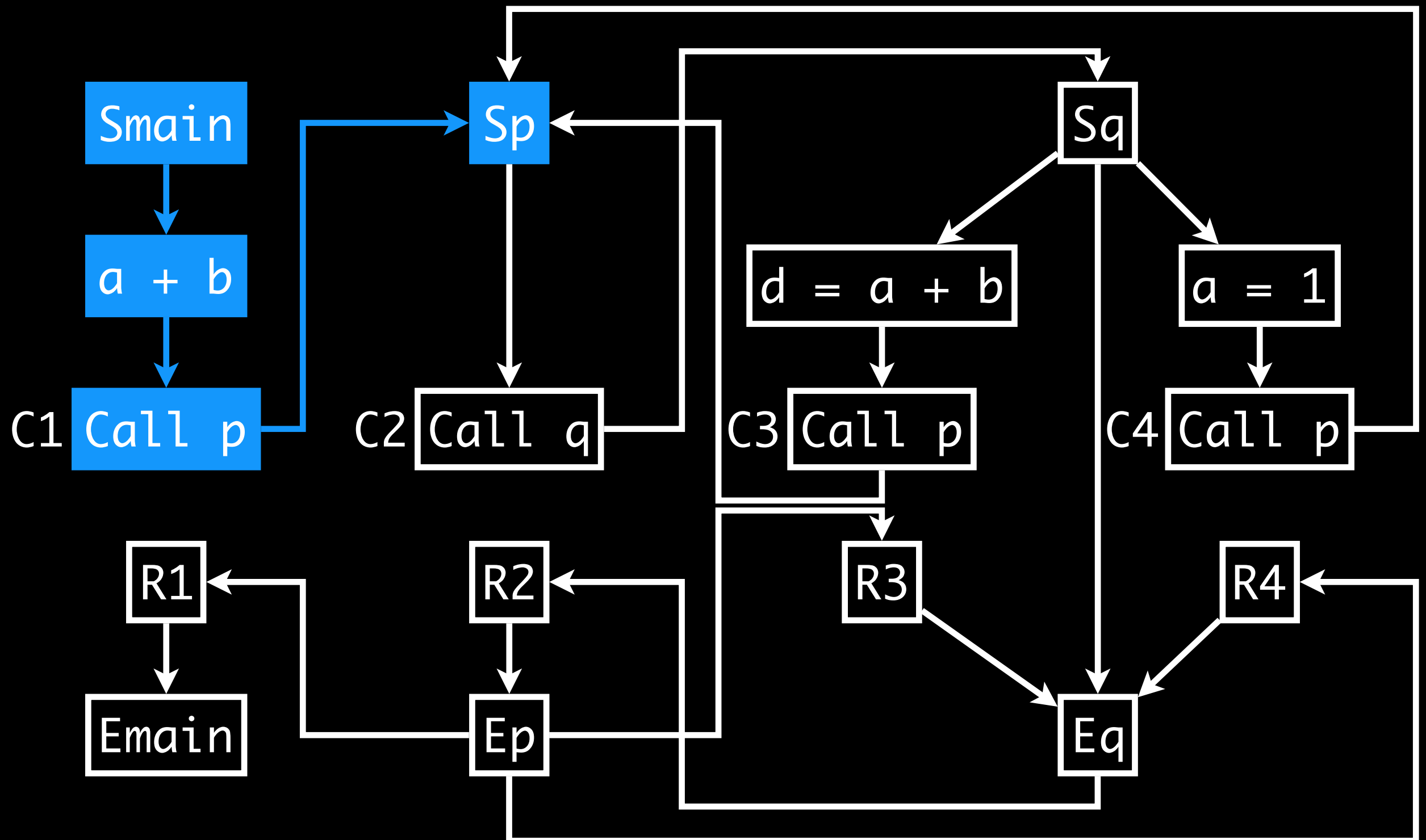
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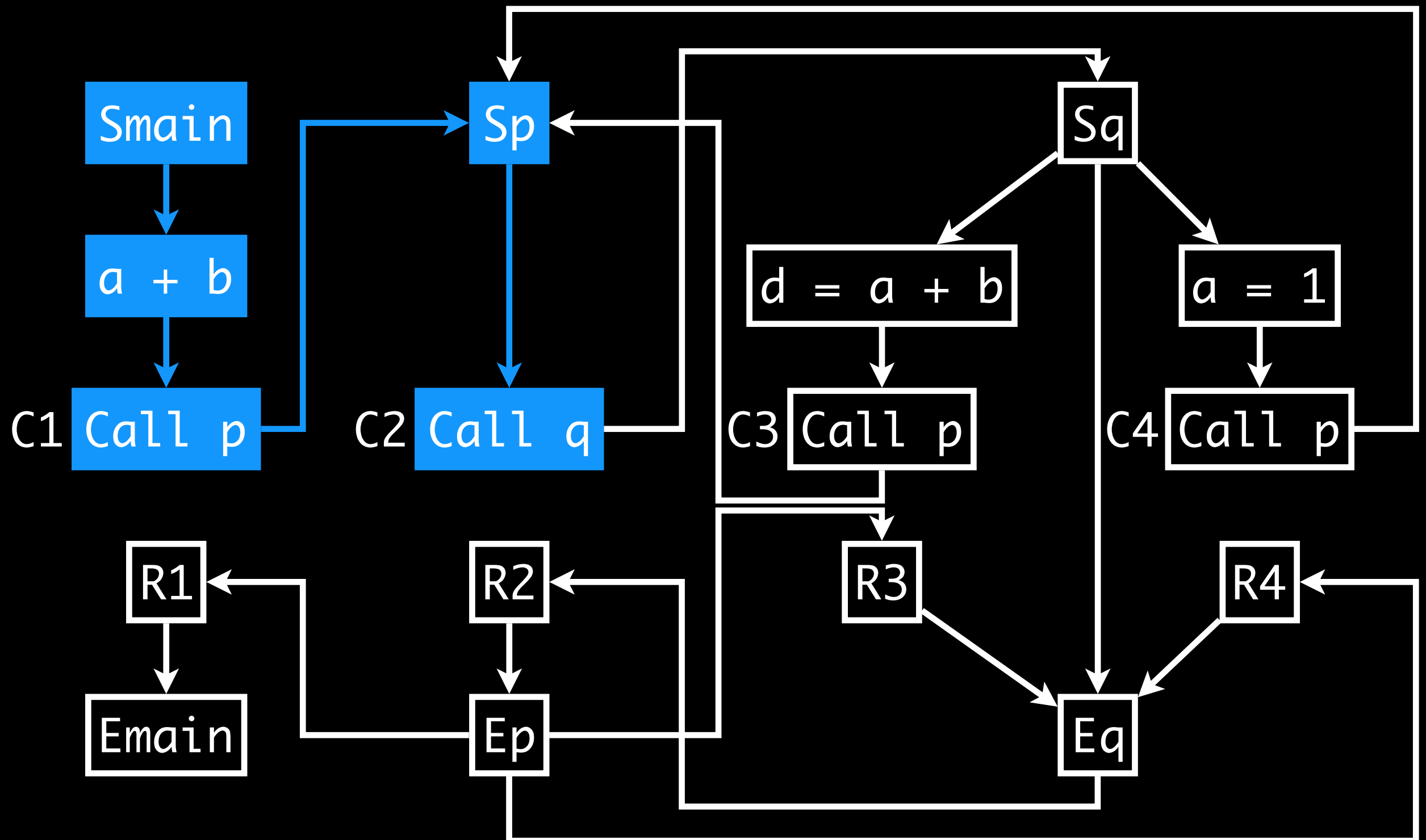
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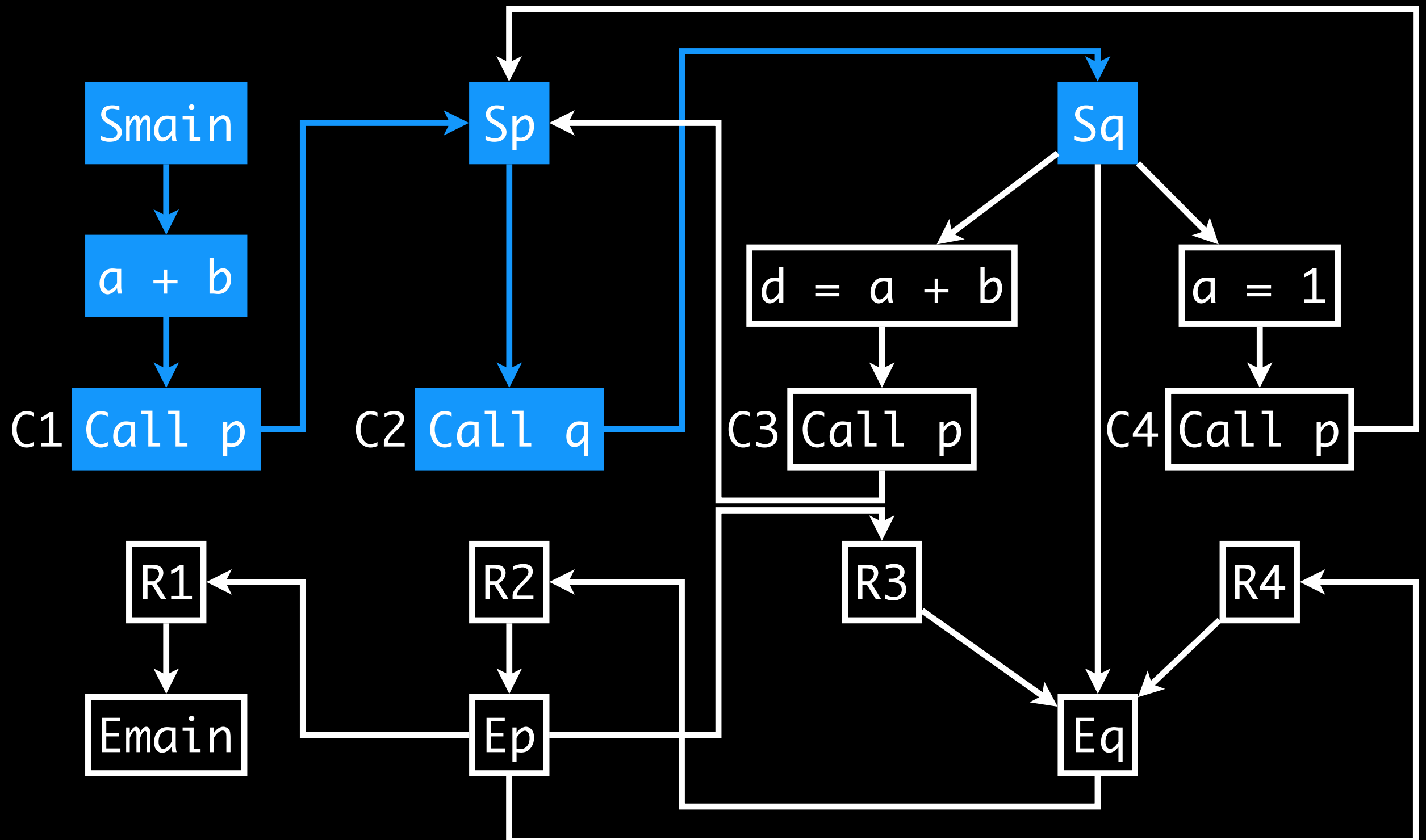
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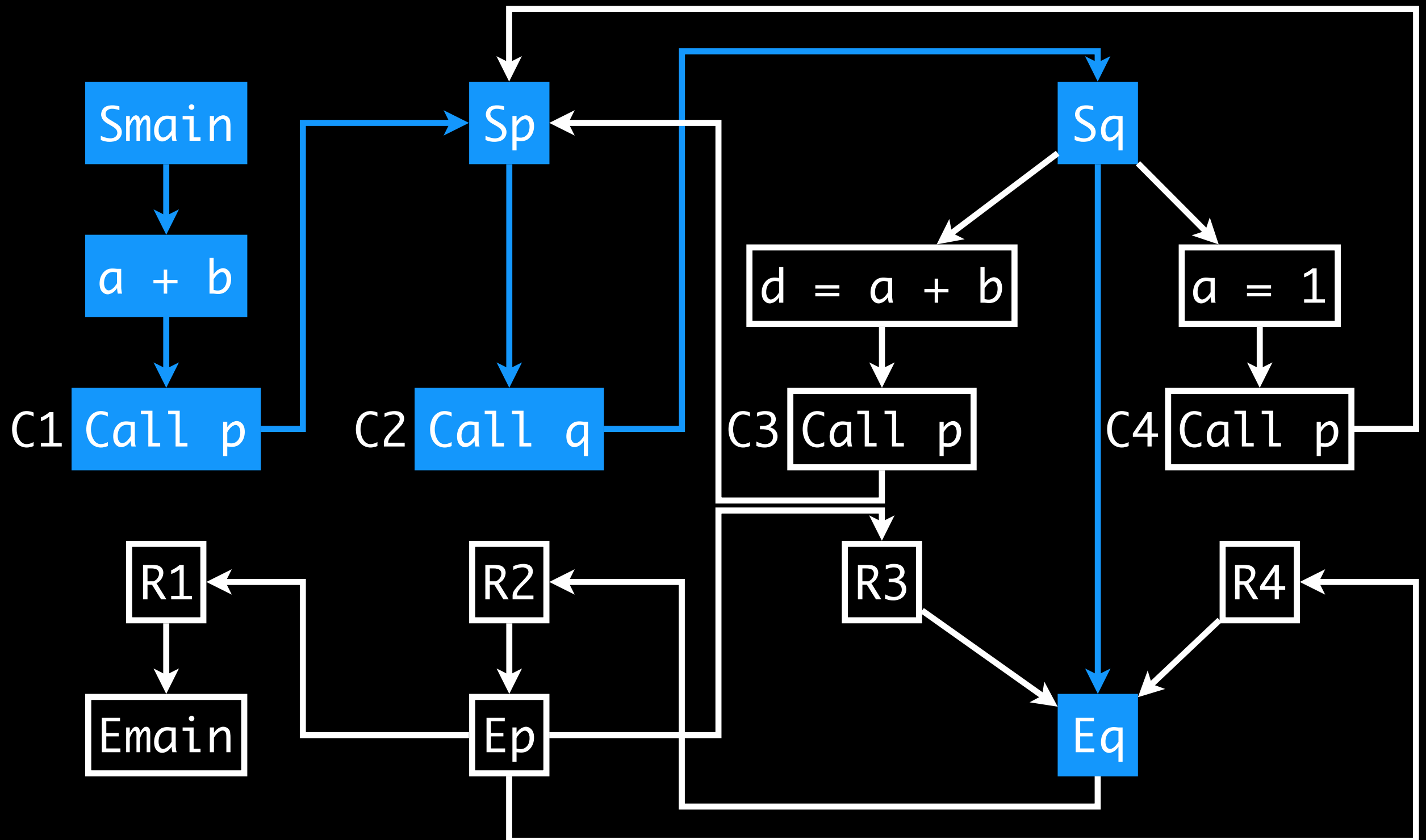
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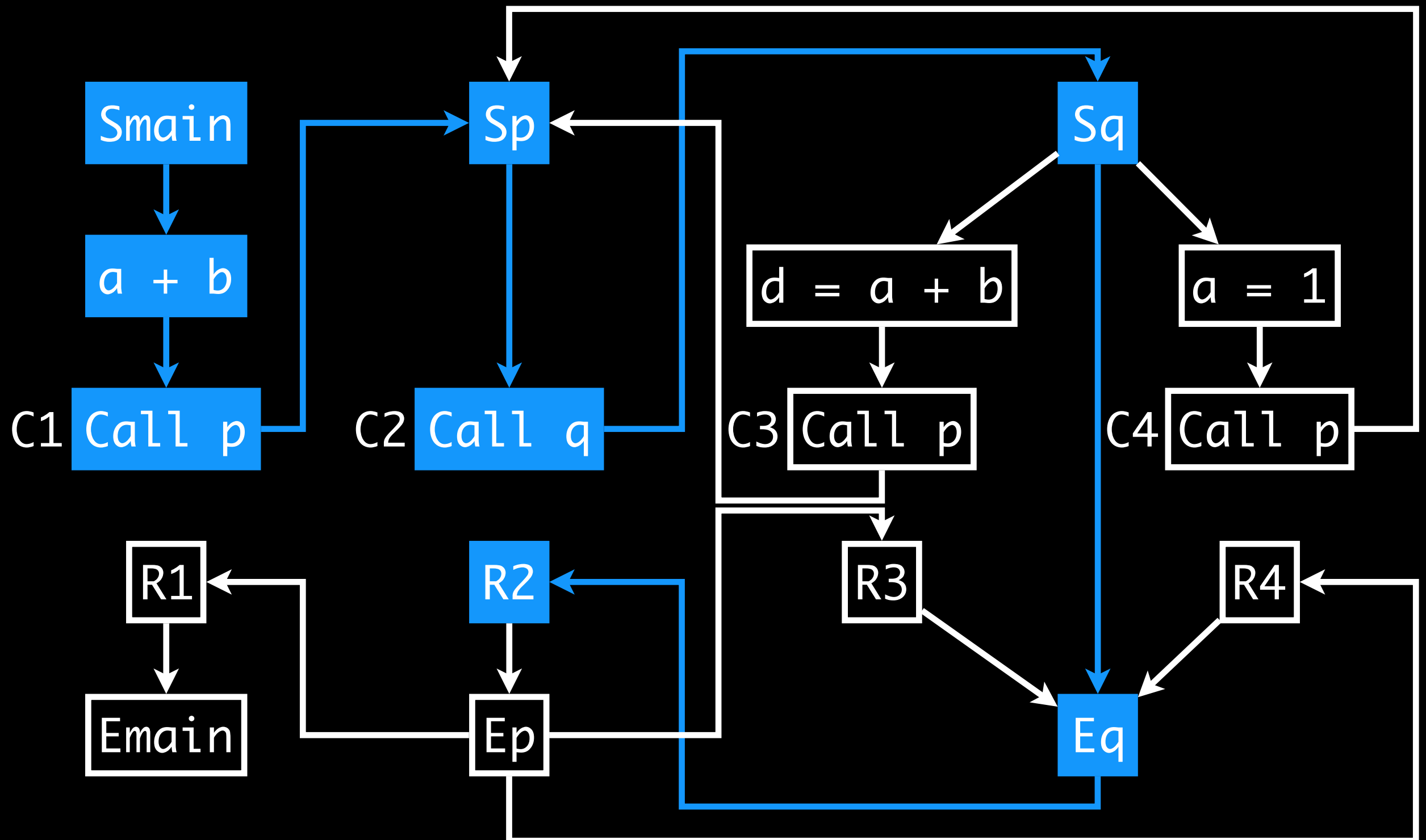
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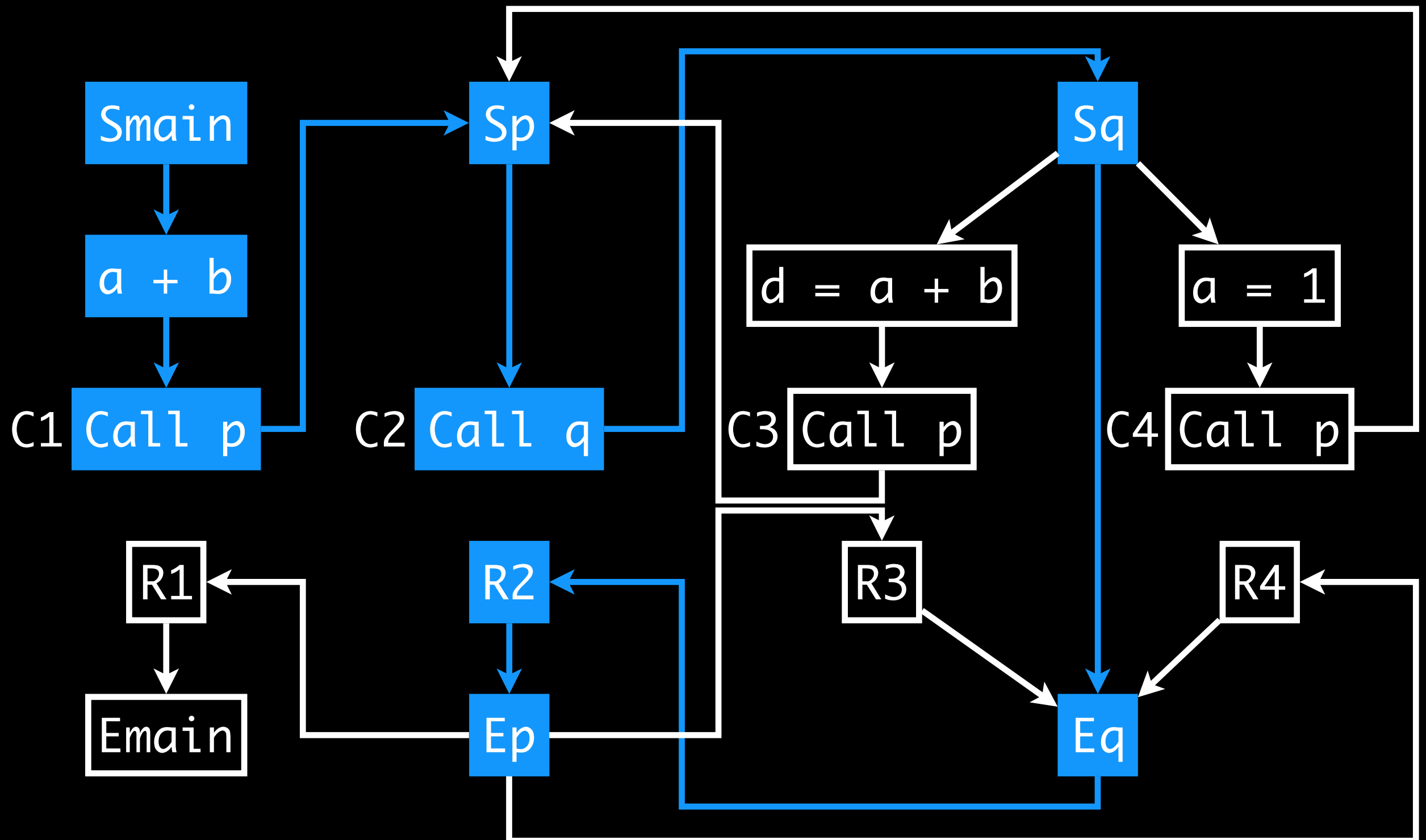
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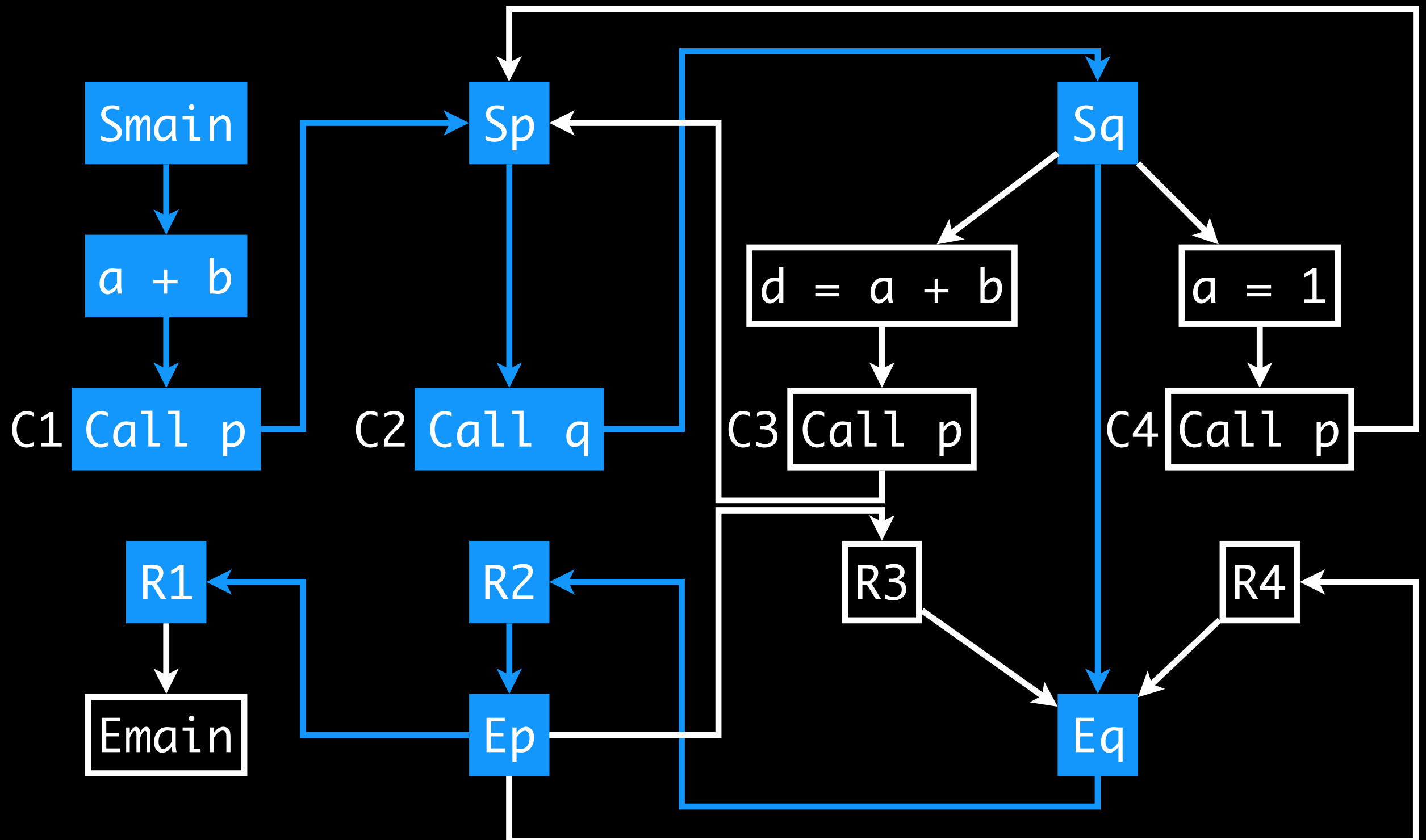


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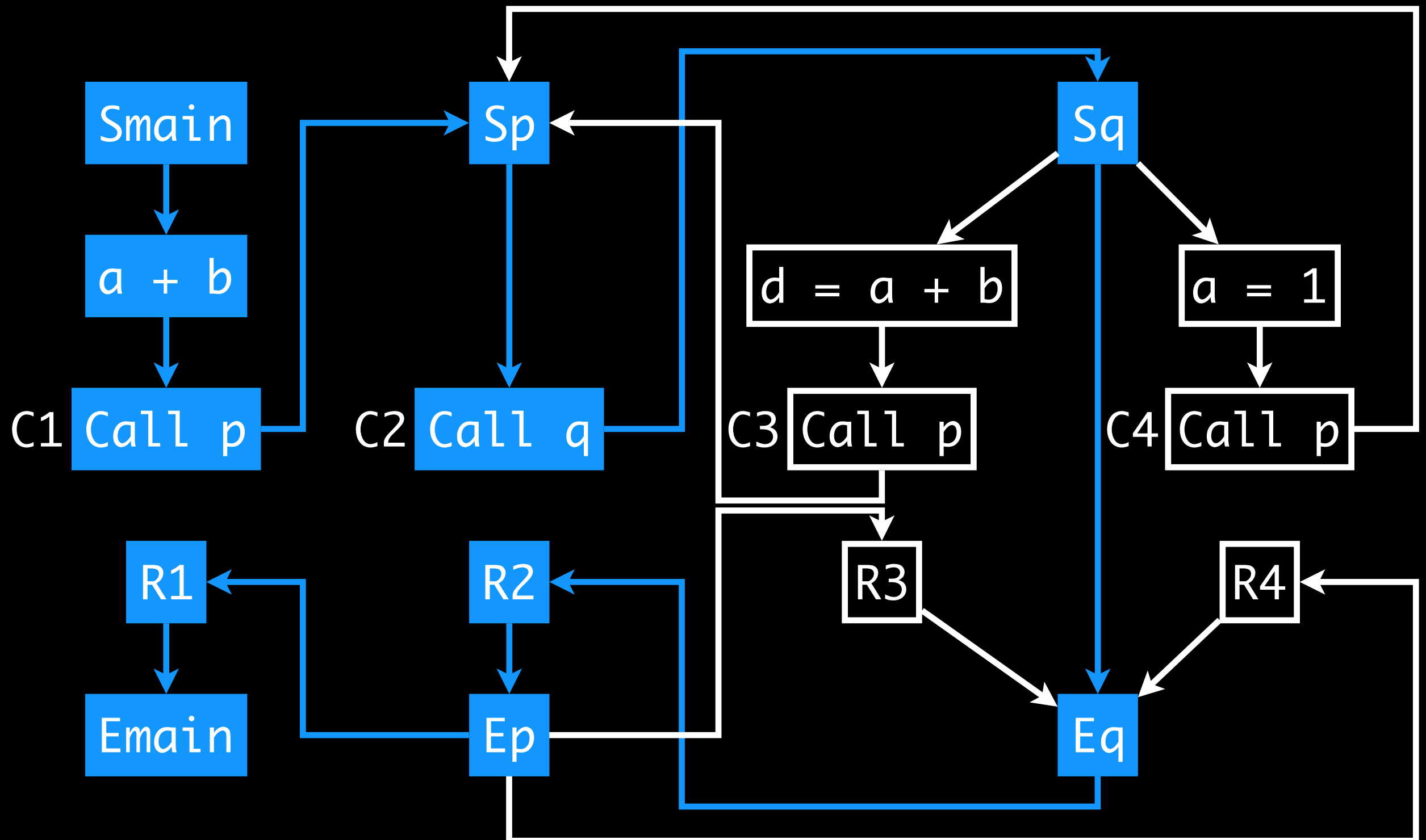




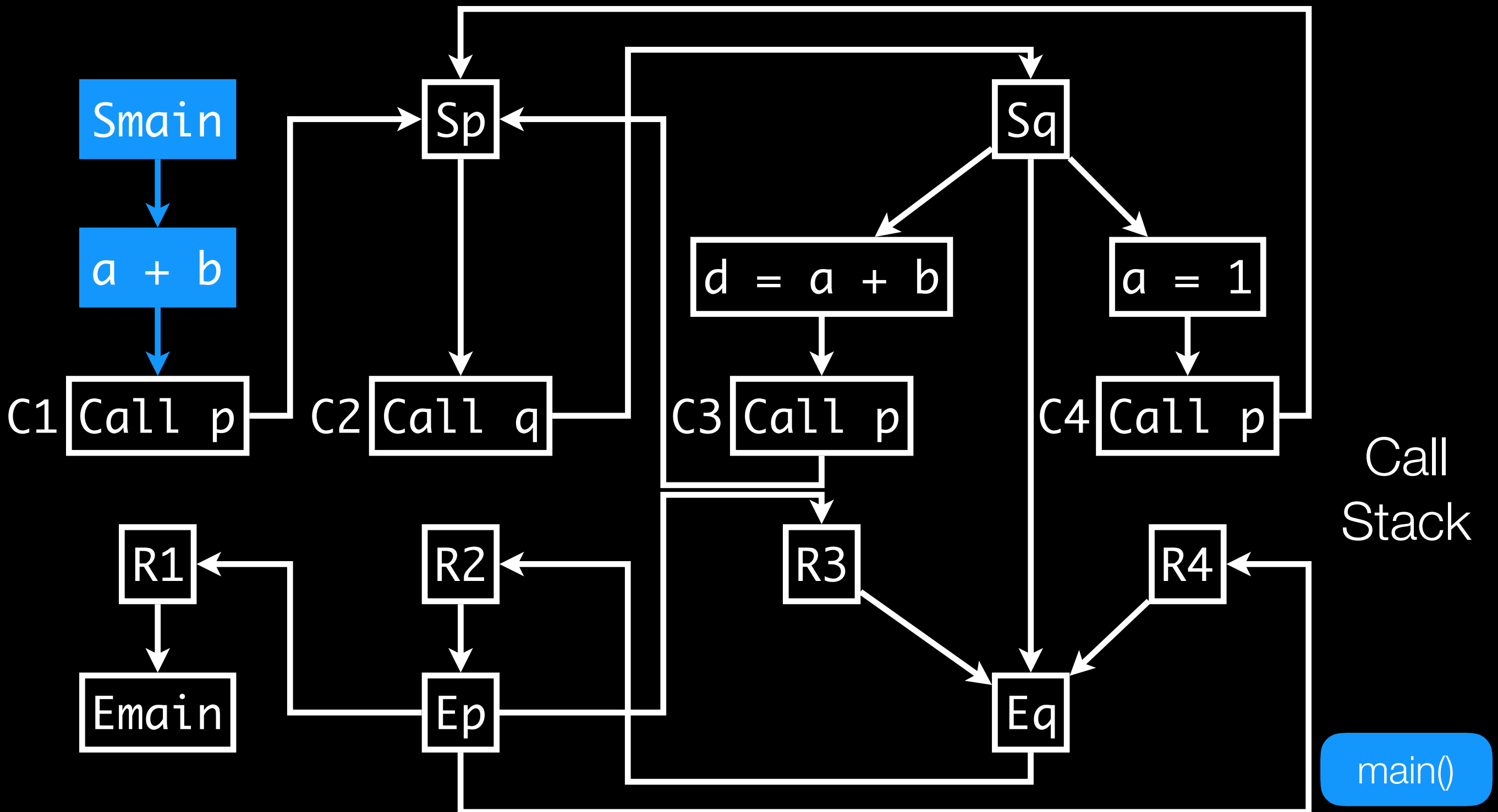
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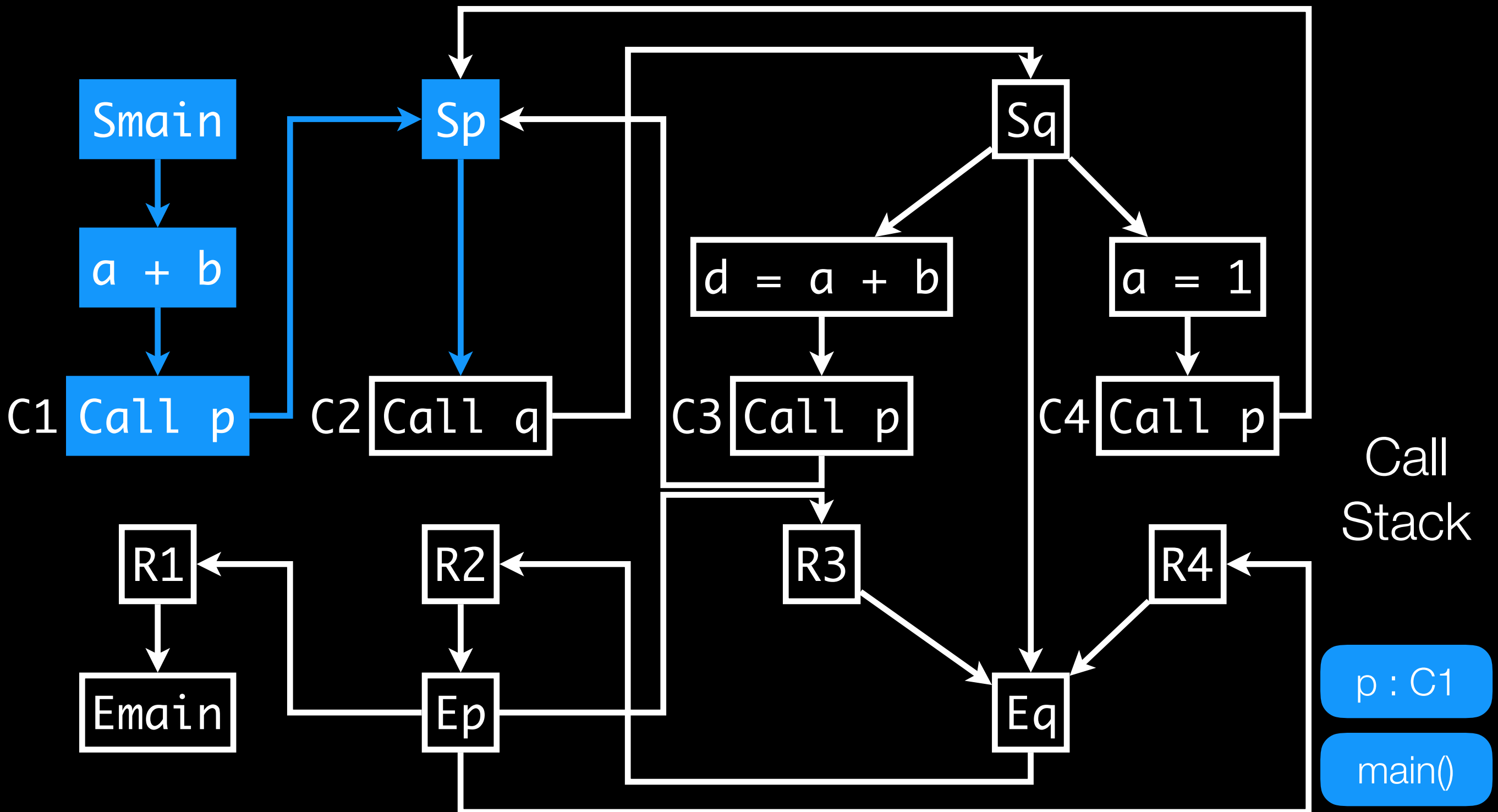
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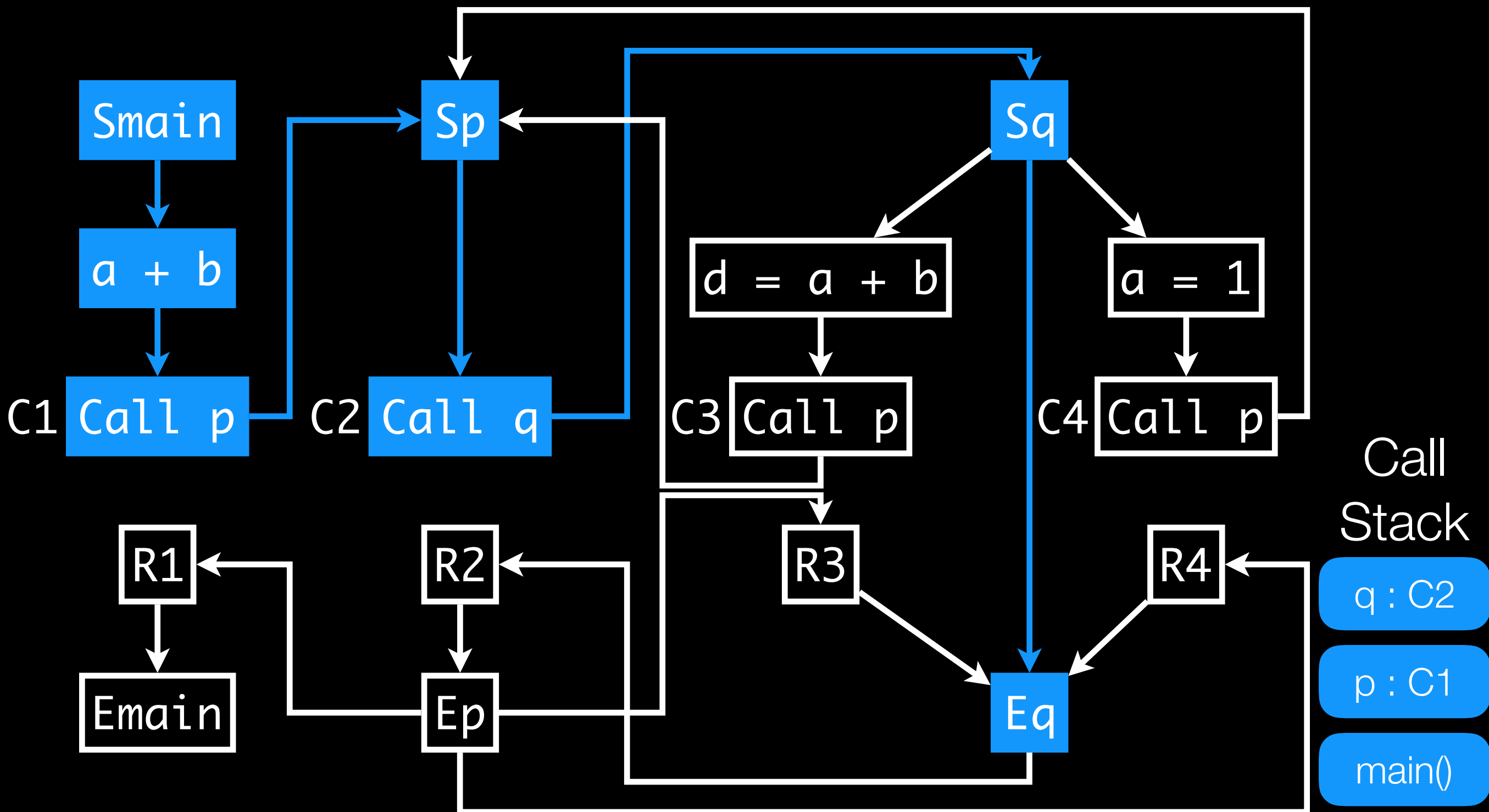
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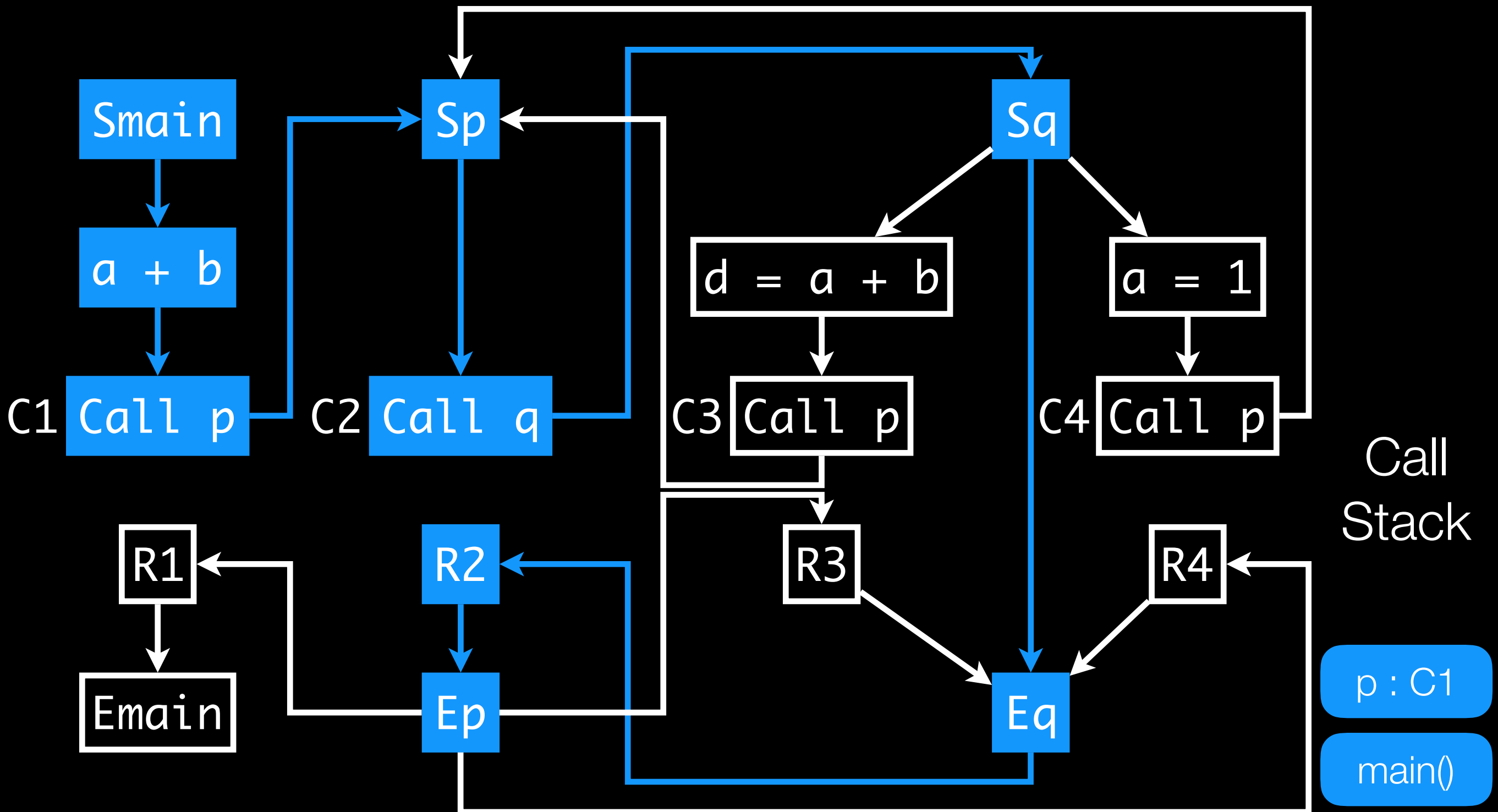
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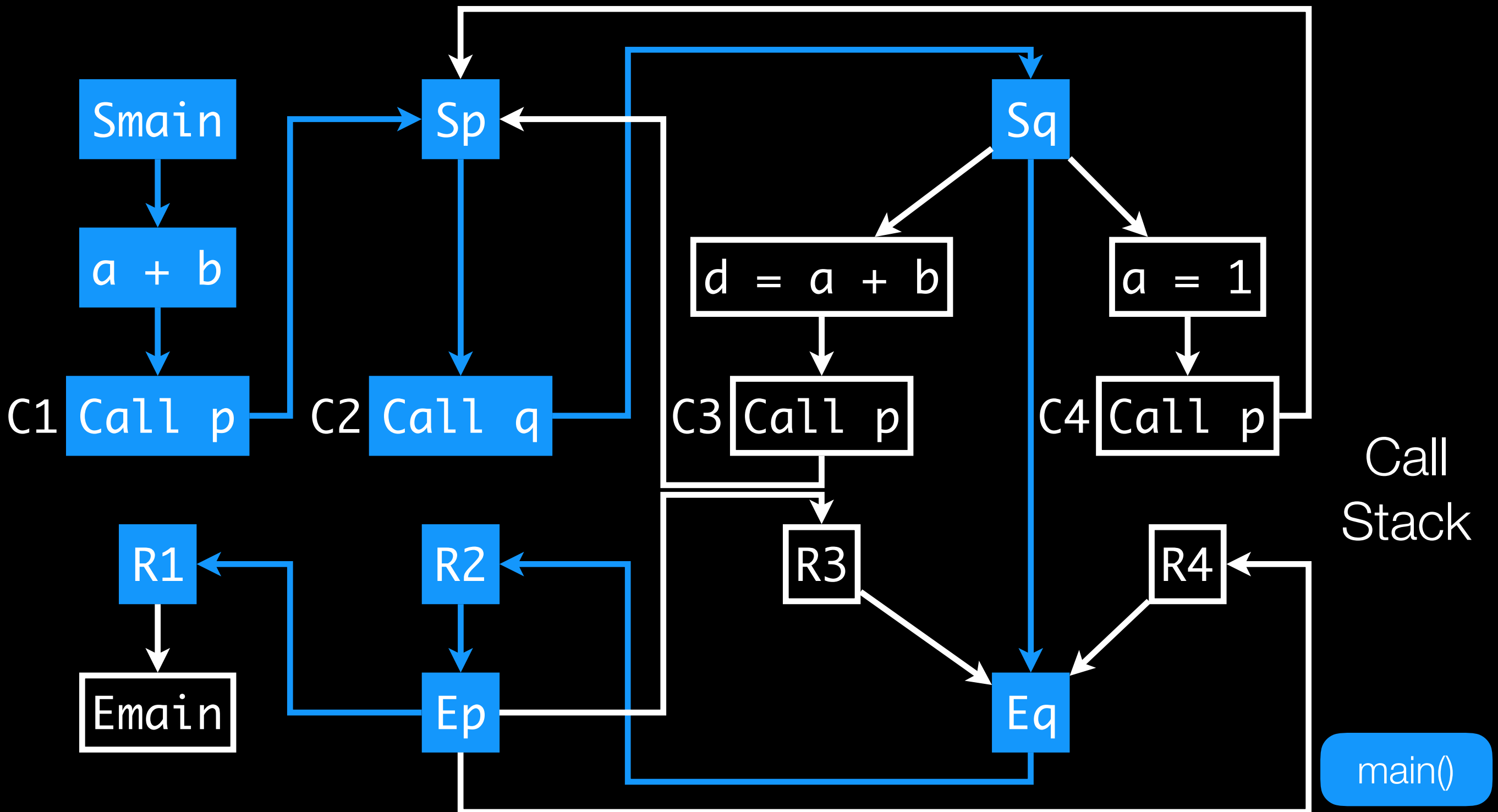
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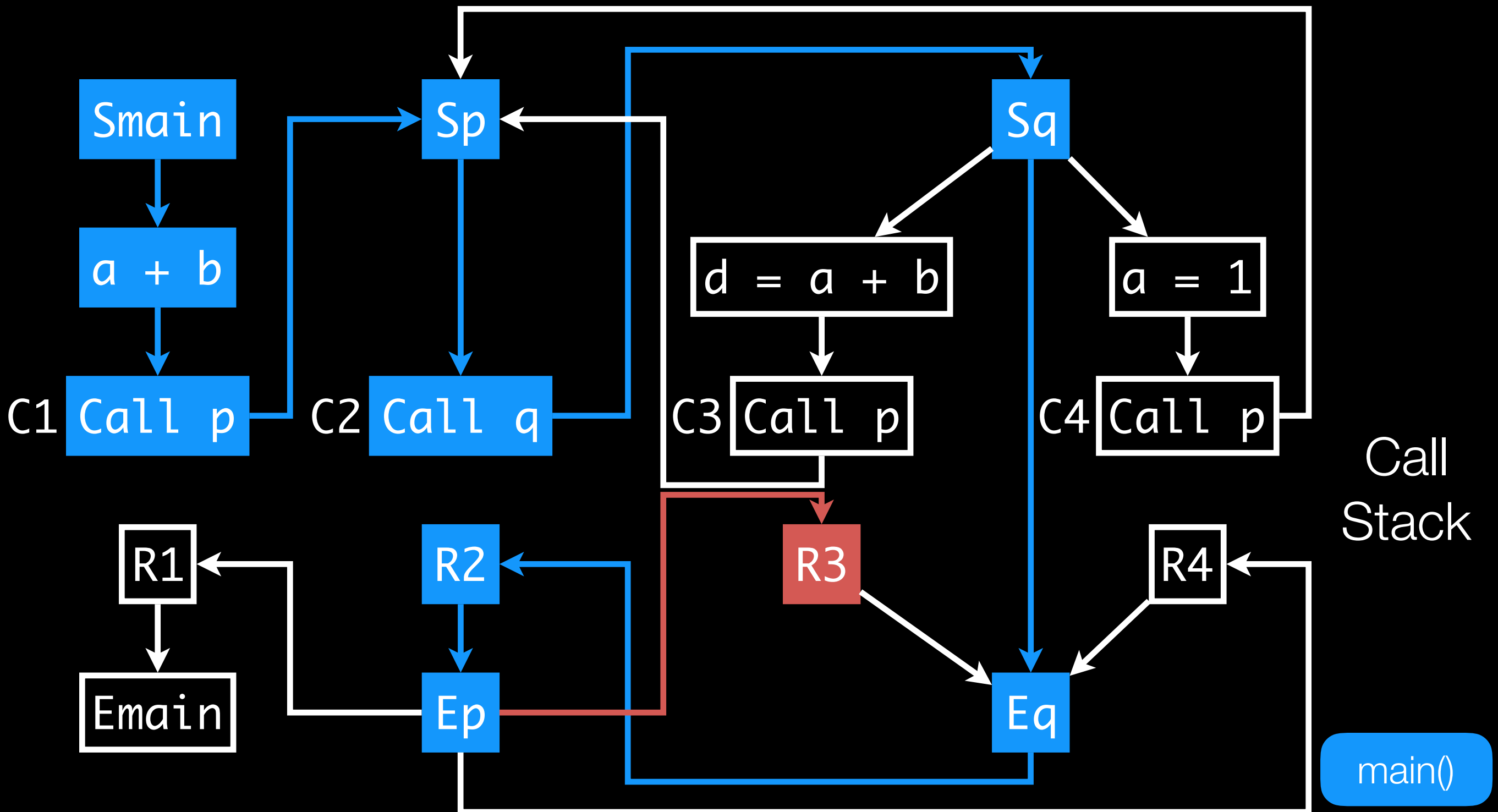
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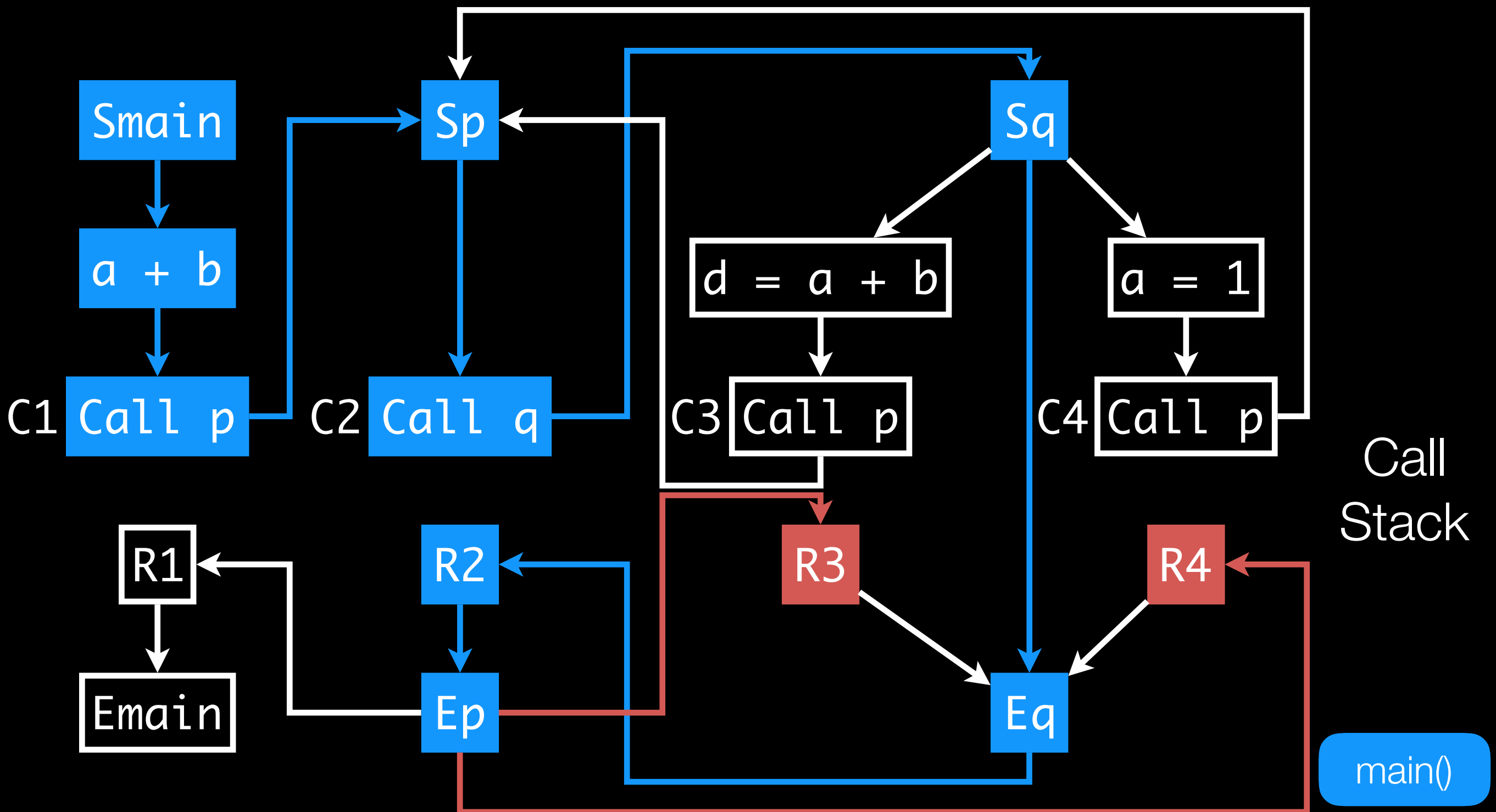


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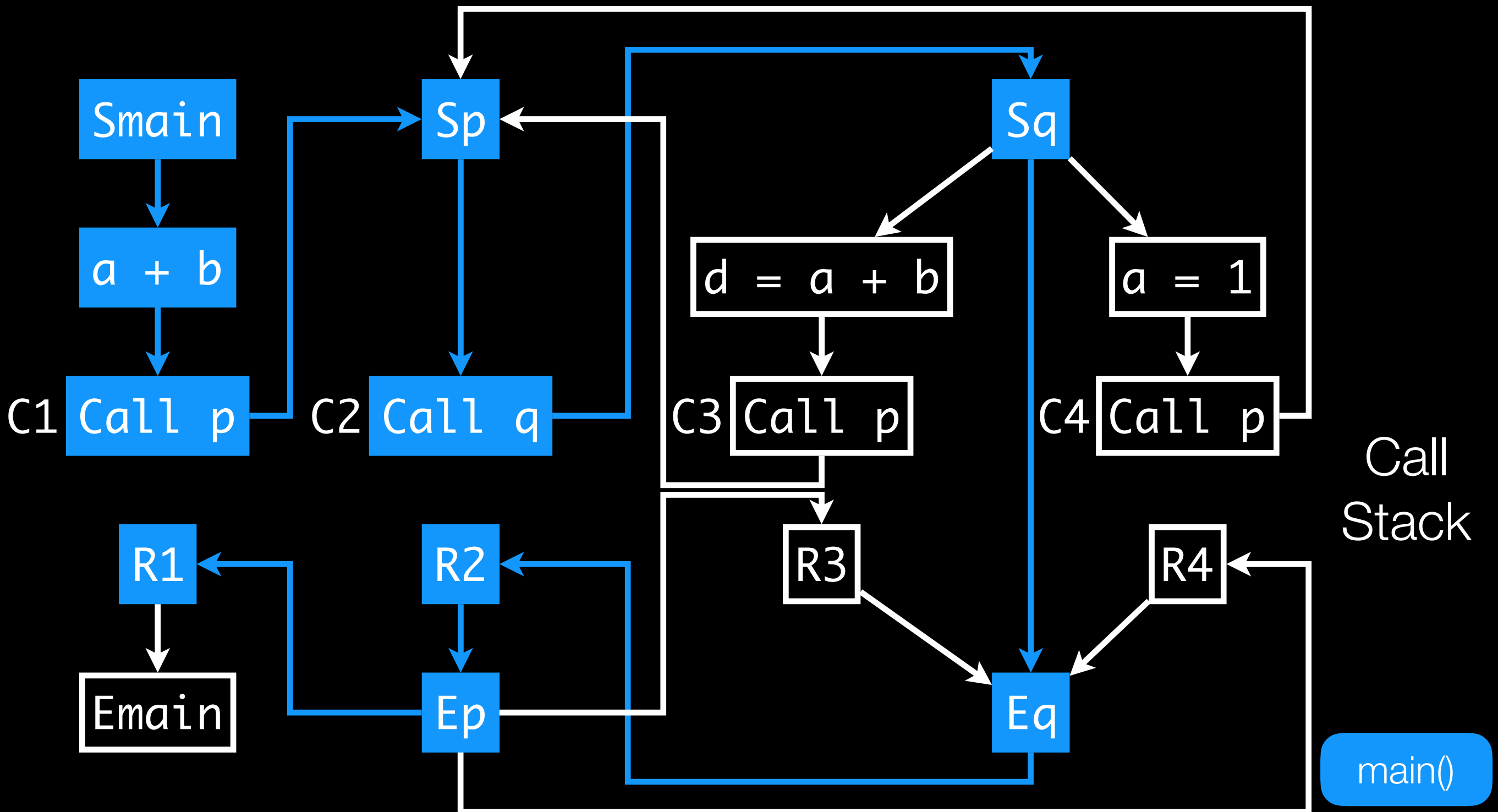




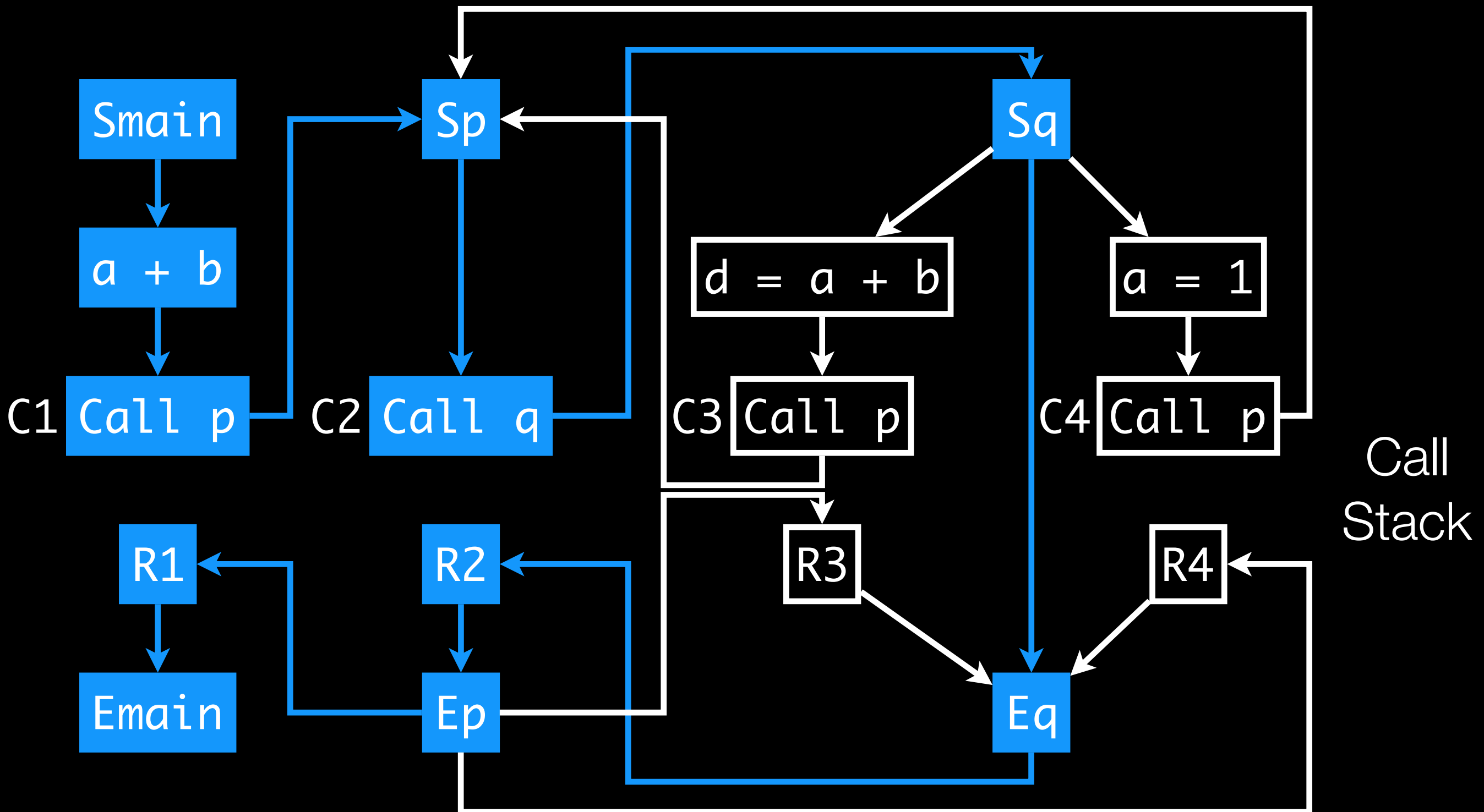
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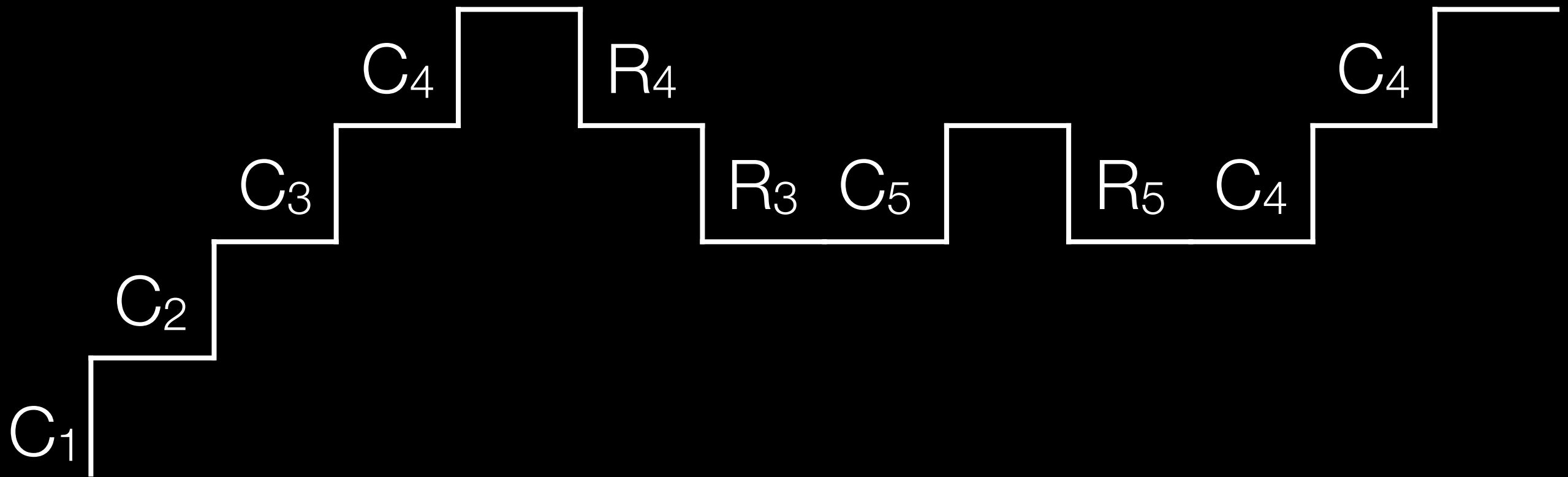


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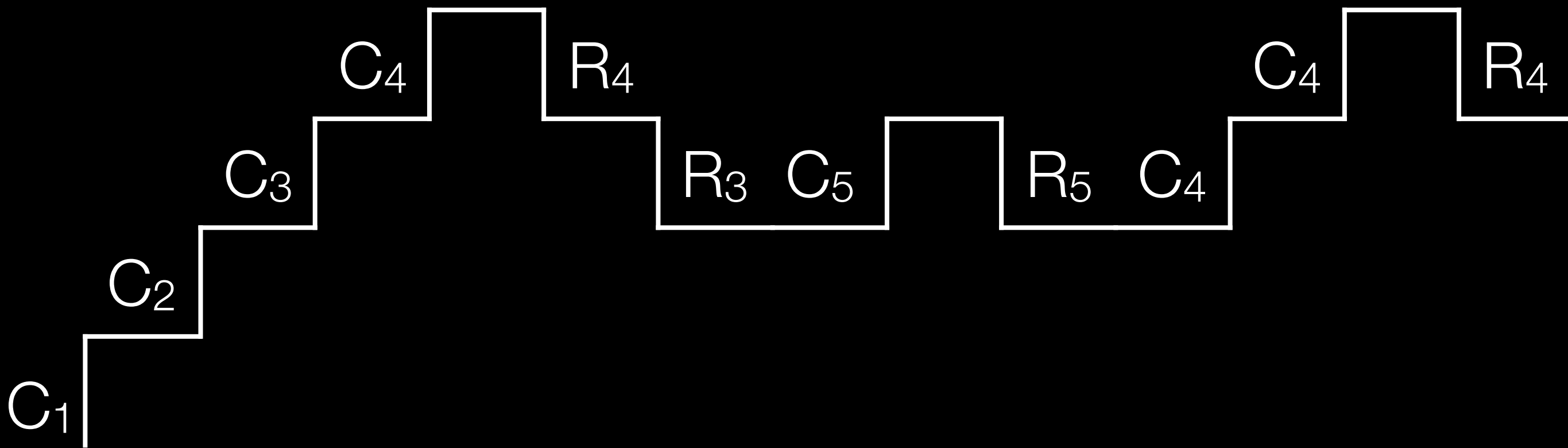
# Recognizing Invalid Paths

## Staircase of Calls & Returns



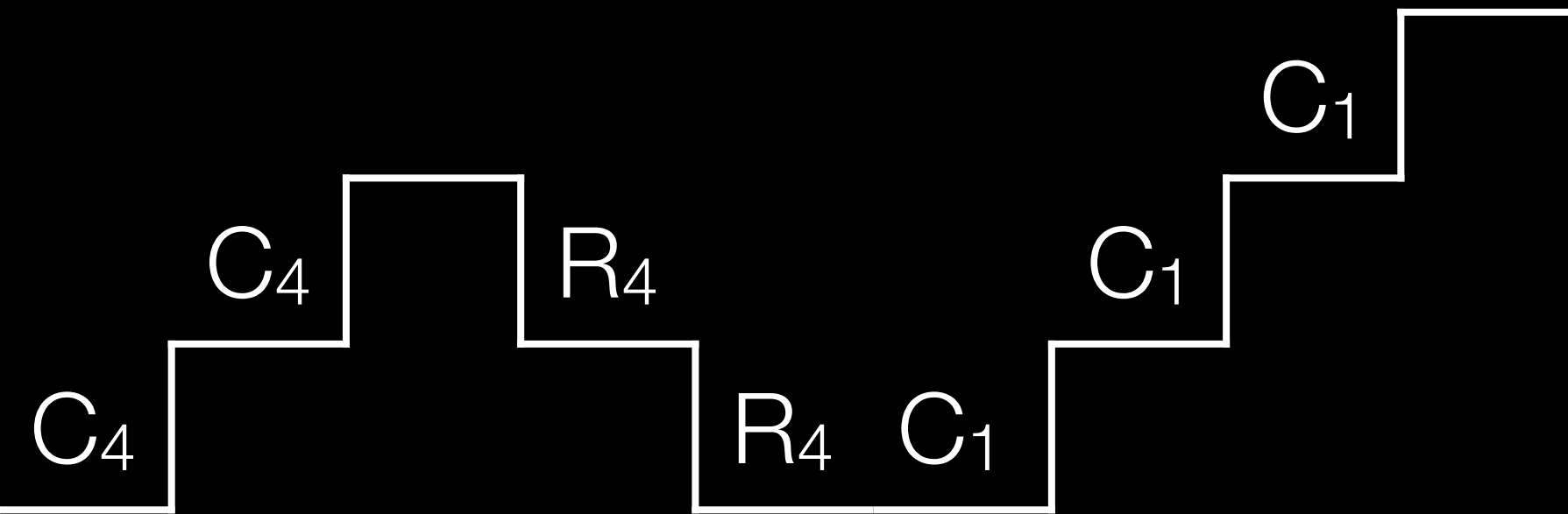
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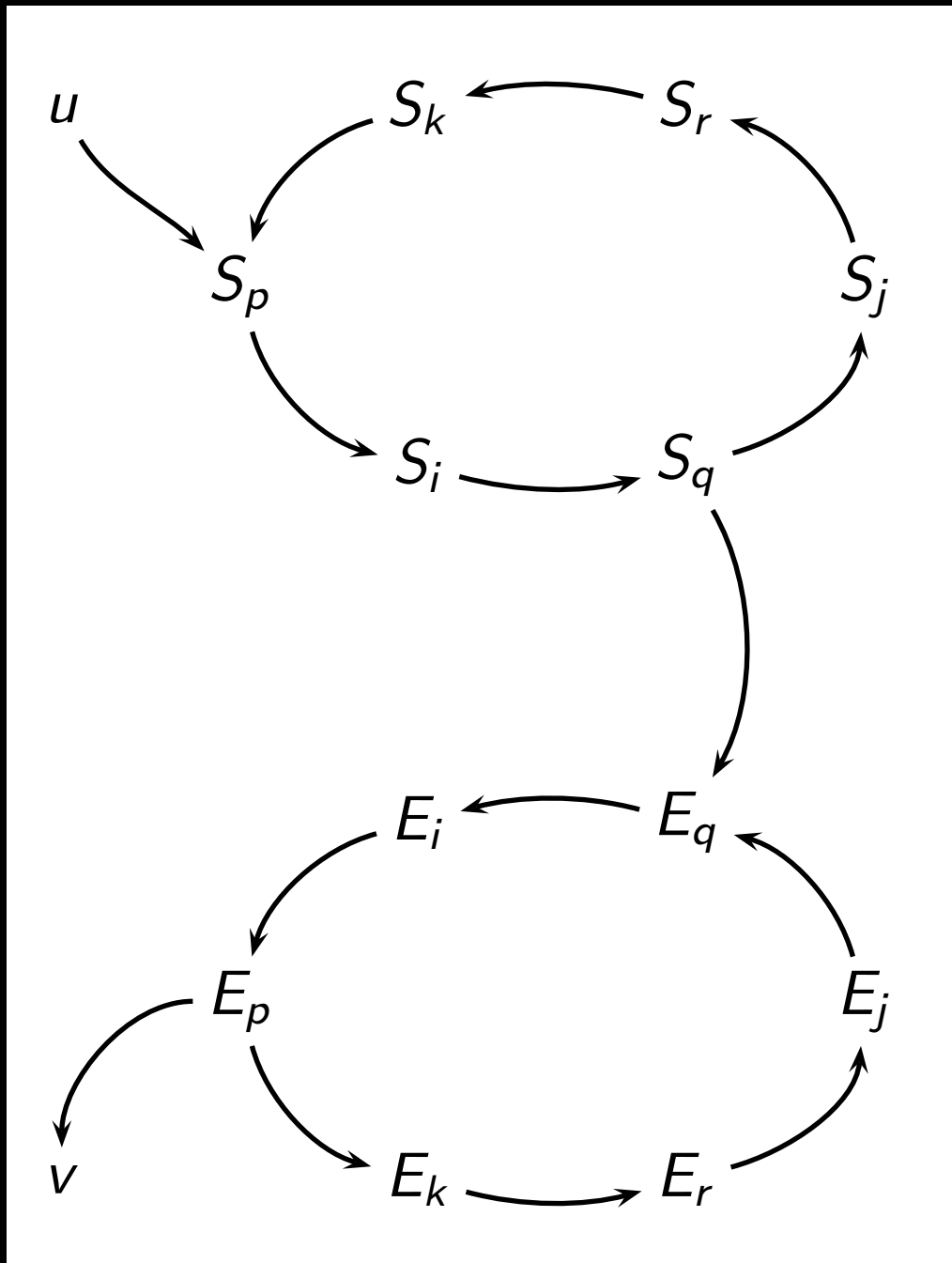
# Recognizing Invalid Paths

## Staircase of Calls & Returns



Every descending step must match  
a corresponding ascending step

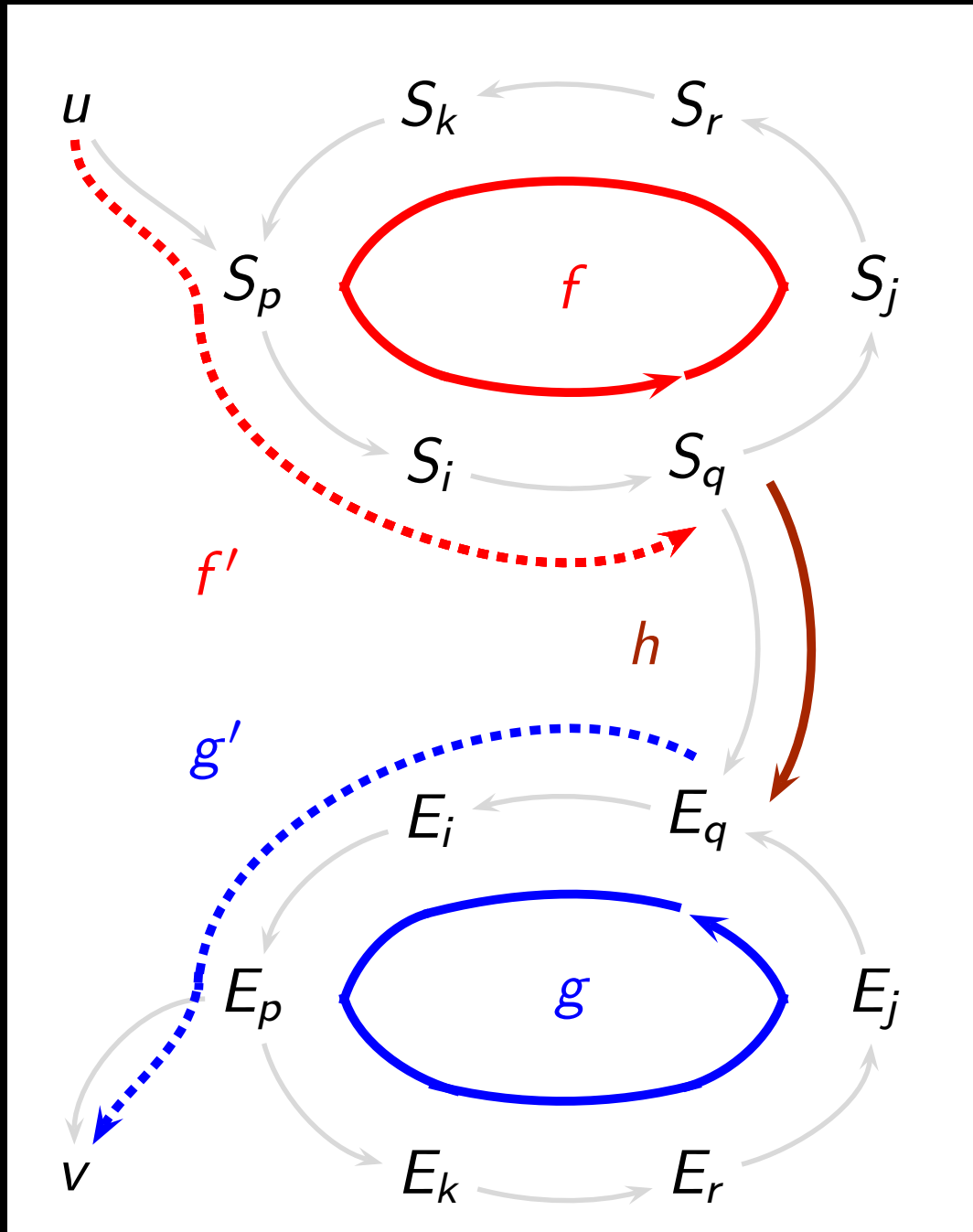
# What About Recursion?



calls

returns

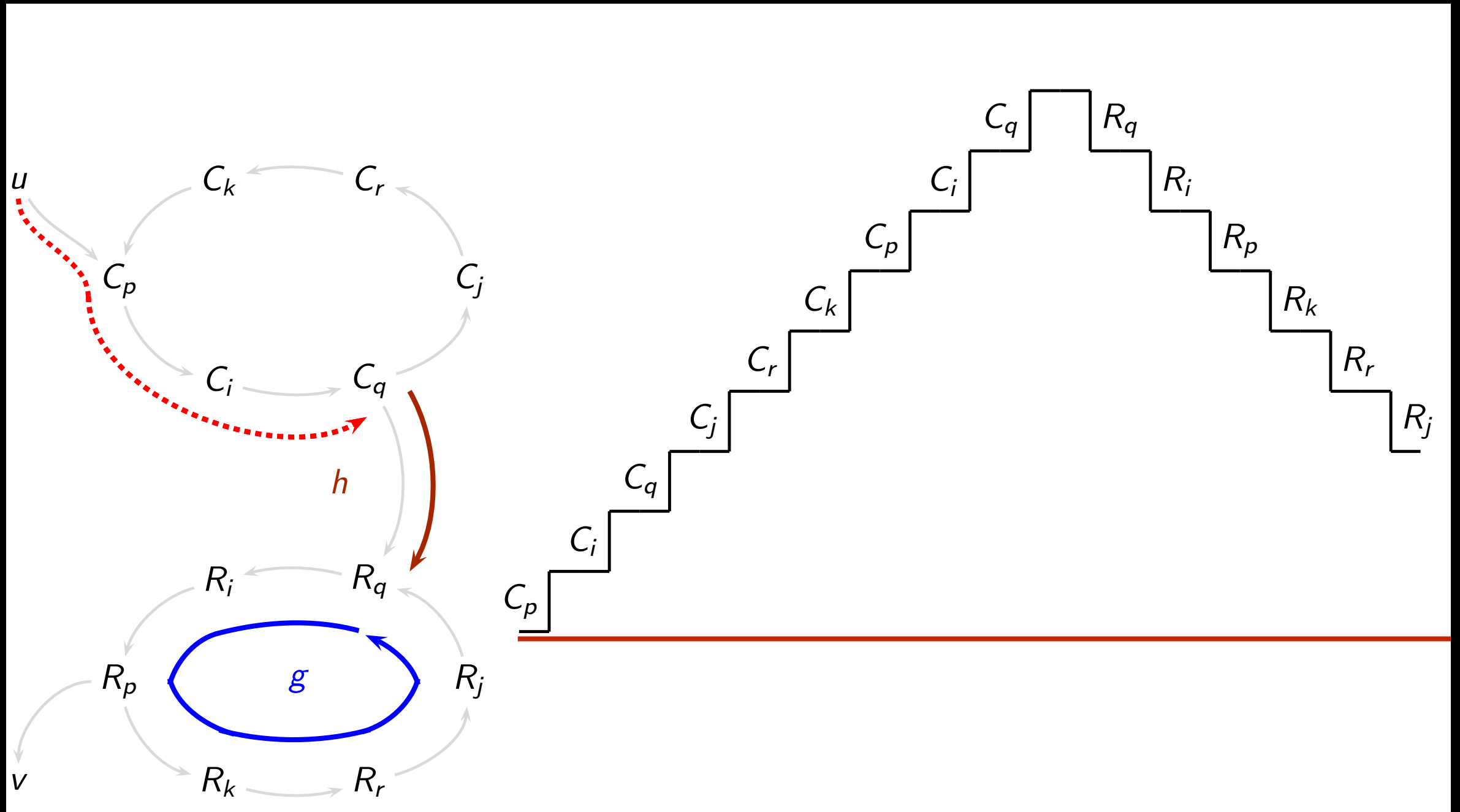
# What About Recursion?



- For a path from  $u$  to  $v$ ,  $g$  must be applied exactly the same number of times as  $f$ .
- For a prefix of the above path,  $g$  can be applied only at most as many times as  $f$ .

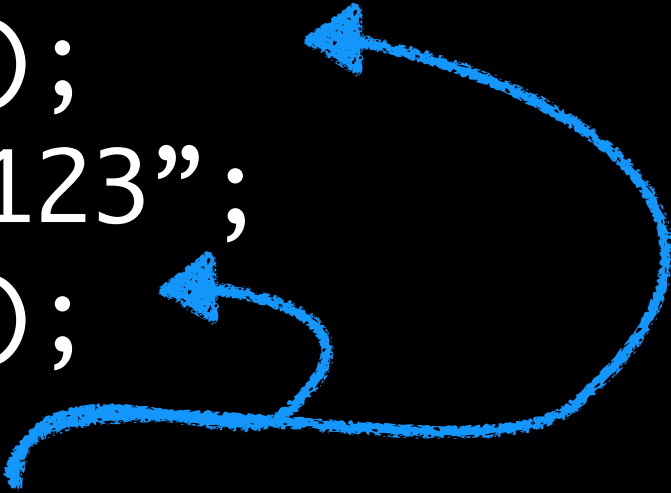


# Staircase of Calls and Returns



# Demand-Driven Analysis

```
main() {  
    s = secret();  
    foo(s);  
    t = "123";  
    foo(t);  
}  
foo(v) { leak(v); }
```



assume we search  
from `foo(v)`  
backwards to find  
possible inputs



here: “unbalanced return” without a call  
must return to all possible callers

Solution =>  
Context-Sensitive Analysis

# Context-Sensitive Analysis

- Analyze the same method, depending on the context of the current call to that method

# Context-Sensitive Analysis

- Considerations:
  - How to distinguish different contexts?
  - Which contexts can be merged?

## Types of Context

- A call string that encodes the methods/call sites on the current call stack
- A value context that uses the input domain values as context
- An object context that uses the currently executing object as context
- and more...

# Important Language Features

# Recursion

- Must bound computation and contexts
- Often uses flow-insensitive analysis to over-approximate



# Parameters/Return Values

- Must map actuals to formals and vice versa
- Don't propagate too much info:
  - at a call: propagate only the facts relevant to that callee
  - at a return: propagate only the facts relevant to the caller
- Question: what to do with static fields?

```
main(){  
    x = source();  
    y = x;  
    z = foo(x);  
}  
  
foo(a) {  
    b = a;  
    return 0;  
}
```

# Aliasing

aliases might be  
created by  
callers and  
callees

```
main(){  
    a.f.g = source();  
    foo(a,b);  
    leak(b.f.g);  
}  
  
foo(x,y) {  
    y.f=x.f;  
}
```

# Virtual Dispatch

- Multiple possible call targets per call site
- Consider them all!
  - “may” or “must” analysis?
- similar to intra-procedural branches at if-then-else constructs (combine)

# Threads

- Intra-procedural analyses are typically sound despite multi-threaded execution
- Inter-procedural analyses are typically *unsound* if flow-sensitive!
- Flow-insensitive analyses not impacted by multi-threading
- Effective modelling of synchronization constructs is a big open research problem!

# Library Dependencies

- Typically analyze an application with its dependencies
- But what about native code?
- Often need to resort to hand-crafted summaries
- Possible way out: summarization (e.g., Averroes)

## Recap

- Context-sensitivity analyzes a method multiple times, once per context
- Challenges: Recursion, parameters, aliasing, virtual dispatch, threads, libraries

Next

- Context sensitivity